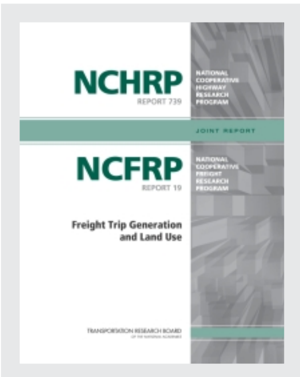
THE NATIONAL ACADEMIES PRESS

This PDF is available at http://nap.edu/23437

SHARE



Freight Trip Generation and Land Use

DETAILS

149 pages | 8.5 x 11 | PAPERBACK
ISBN 978-0-309-37520-7 | DOI 10.17226/23437

BUY THIS BOOK

FIND RELATED TITLES

AUTHORS

Holguín-Veras, José; Jaller, Miguel; Sanchez-Diaz, Ivan; Wojtowicz, Jeffrey; Campbell, Shama; Levinson, Herbert; Lawson, Catherine; Powers, Erica Levine; and Tavasszy, Lorant

Visit the National Academies Press at NAP.edu and login or register to get:

- Access to free PDF downloads of thousands of scientific reports
- 10% off the price of print titles
- Email or social media notifications of new titles related to your interests
- Special offers and discounts

Distribution, posting, or copying of this PDF is strictly prohibited without written permission of the National Academies Press. (Request Permission) Unless otherwise indicated, all materials in this PDF are copyrighted by the National Academy of Sciences.

Copyright © National Academy of Sciences. All rights reserved.

NATIONAL COOPERATIVE HIGHWAY RESEARCH PROGRAM

NCHRP REPORT 739

NATIONAL COOPERATIVE FREIGHT RESEARCH PROGRAM

NCFRP REPORT 19

Freight Trip Generation and Land Use

José Holguín-Veras
Miguel Jaller
Ivan Sanchez-Diaz
Jeffrey Wojtowicz
Shama Campbell
Herbert Levinson
RENSSELAER POLYTECHNIC INSTITUTE
Troy, NY

Catherine Lawson
Erica Levine Powers
UNIVERSITY AT ALBANY
Albany, NY

Lorant Tavasszy
TNO DELFT
Delft, Netherlands

Subscriber Categories

Motor Carriers • Freight Transportation • Planning and Forecasting

Research sponsored by the Research and Innovative Technology Administration

TRANSPORTATION RESEARCH BOARD

WASHINGTON, D.C.
2012
www.TRB.org

Copyright National Academy of Sciences. All rights reserved.

NATIONAL COOPERATIVE HIGHWAY RESEARCH PROGRAM

Systematic, well-designed research provides the most effective approach to the solution of many problems facing highway administrators and engineers. Often, highway problems are of local interest and can best be studied by highway departments individually or in cooperation with their state universities and others. However, the accelerating growth of highway transportation develops increasingly complex problems of wide interest to highway authorities. These problems are best studied through a coordinated program of cooperative research.

In recognition of these needs, the highway administrators of the American Association of State Highway and Transportation Officials initiated in 1962 an objective national highway research program employing modern scientific techniques. This program is supported on a continuing basis by funds from participating member states of the Association and it receives the full cooperation and support of the Federal Highway Administration, United States Department of Transportation.

The Transportation Research Board of the National Academies was requested by the Association to administer the research program because of the Board's recognized objectivity and understanding of modern research practices. The Board is uniquely suited for this purpose as it maintains an extensive committee structure from which authorities on any highway transportation subject may be drawn; it possesses avenues of communications and cooperation with federal, state and local governmental agencies, universities, and industry; its relationship to the National Research Council is an insurance of objectivity; it maintains a full-time research correlation staff of specialists in highway transportation matters to bring the findings of research directly to those who are in a position to use them.

The program is developed on the basis of research needs identified by chief administrators of the highway and transportation departments and by committees of AASHTO. Each year, specific areas of research needs to be included in the program are proposed to the National Research Council and the Board by the American Association of State Highway and Transportation Officials. Research projects to fulfill these needs are defined by the Board, and qualified research agencies are selected from those that have submitted proposals. Administration and surveillance of research contracts are the responsibilities of the National Research Council and the Transportation Research Board.

The needs for highway research are many, and the National Cooperative Highway Research Program can make significant contributions to the solution of highway transportation problems of mutual concern to many responsible groups. The program, however, is intended to complement rather than to substitute for or duplicate other highway research programs.

NCHRP REPORT 739

Project 08-80
ISSN 0077-5614
ISBN 978-0-309-25878-4
Library of Congress Control Number 2012954681

© 2012 National Academy of Sciences. All rights reserved.

COPYRIGHT INFORMATION

Authors herein are responsible for the authenticity of their materials and for obtaining written permissions from publishers or persons who own the copyright to any previously published or copyrighted material used herein.

Cooperative Research Programs (CRP) grants permission to reproduce material in this publication for classroom and not-for-profit purposes. Permission is given with the understanding that none of the material will be used to imply TRB, AASHTO, FAA, FHWA, FMCSA, FTA, or Transit Development Corporation endorsement of a particular product, method, or practice. It is expected that those reproducing the material in this document for educational and not-for-profit uses will give appropriate acknowledgment of the source of any reprinted or reproduced material. For other uses of the material, request permission from CRP.

NOTICE

The project that is the subject of this report was a part of the National Cooperative Highway Research Program, conducted by the Transportation Research Board with the approval of the Governing Board of the National Research Council.

The members of the technical panel selected to monitor this project and to review this report were chosen for their special competencies and with regard for appropriate balance. The report was reviewed by the technical panel and accepted for publication according to procedures established and overseen by the Transportation Research Board and approved by the Governing Board of the National Research Council.

The opinions and conclusions expressed or implied in this report are those of the researchers who performed the research and are not necessarily those of the Transportation Research Board, the National Research Council, or the program sponsors.

The Transportation Research Board of the National Academies, the National Research Council, and the sponsors of the National Cooperative Highway Research Program do not endorse products or manufacturers. Trade or manufacturers' names appear herein solely because they are considered essential to the object of the report.

Published reports of the

NATIONAL COOPERATIVE HIGHWAY RESEARCH PROGRAM

are available from:

Transportation Research Board
Business Office
500 Fifth Street, NW
Washington, DC 20001

and can be ordered through the Internet at:

http://www.national-academies.org/trb/bookstore

Printed in the United States of America

Copyright National Academy of Sciences. All rights reserved.

NATIONAL COOPERATIVE FREIGHT RESEARCH PROGRAM

America's freight transportation system makes critical contributions to the nation's economy, security, and quality of life. The freight transportation system in the United States is a complex, decentralized, and dynamic network of private and public entities, involving all modes of transportation—trucking, rail, waterways, air, and pipelines. In recent years, the demand for freight transportation service has been increasing fueled by growth in international trade; however, bottlenecks or congestion points in the system are exposing the inadequacies of current infrastructure and operations to meet the growing demand for freight. Strategic operational and investment decisions by governments at all levels will be necessary to maintain freight system performance, and will in turn require sound technical guidance based on research.

The National Cooperative Freight Research Program (NCFRP) is a cooperative research program sponsored by the Research and Innovative Technology Administration (RITA) under Grant No. DTOS59-06-G-00039 and administered by the Transportation Research Board (TRB). The program was authorized in 2005 with the passage of the Safe, Accountable, Flexible, Efficient Transportation Equity Act: A Legacy for Users (SAFETEA-LU). On September 6, 2006, a contract to begin work was executed between RITA and The National Academies. The NCFRP will carry out applied research on problems facing the freight industry that are not being adequately addressed by existing research programs.

Program guidance is provided by an Oversight Committee comprised of a representative cross section of freight stakeholders appointed by the National Research Council of The National Academies. The NCFRP Oversight Committee meets annually to formulate the research program by identifying the highest priority projects and defining funding levels and expected products. Research problem statements recommending research needs for consideration by the Oversight Committee are solicited annually, but may be submitted to TRB at any time. Each selected project is assigned to a panel, appointed by TRB, which provides technical guidance and counsel throughout the life of the project. Heavy emphasis is placed on including members representing the intended users of the research products.

The NCFRP will produce a series of research reports and other products such as guidebooks for practitioners. Primary emphasis will be placed on disseminating NCFRP results to the intended end-users of the research: freight shippers and carriers, service providers, suppliers, and public officials.

NCFRP REPORT 19

Project NCFRP-25
ISSN 1947-5659
ISBN 978-0-309-25878-4
Library of Congress Control Number 2012954681

© 2012 National Academy of Sciences. All rights reserved.

COPYRIGHT INFORMATION

Authors herein are responsible for the authenticity of their materials and for obtaining written permissions from publishers or persons who own the copyright to any previously published or copyrighted material used herein.

Cooperative Research Programs (CRP) grants permission to reproduce material in this publication for classroom and not-for-profit purposes. Permission is given with the understanding that none of the material will be used to imply TRB, AASHTO, FAA, FHWA, FMCSA, FTA, RITA, or PHMSA endorsement of a particular product, method, or practice. It is expected that those reproducing the material in this document for educational and not-for-profit uses will give appropriate acknowledgment of the source of any reprinted or reproduced material. For other uses of the material, request permission from CRP.

NOTICE

The project that is the subject of this report was a part of the National Cooperative Freight Research Program, conducted by the Transportation Research Board with the approval of the Governing Board of the National Research Council.

The members of the technical panel selected to monitor this project and to review this report were chosen for their special competencies and with regard for appropriate balance. The report was reviewed by the technical panel and accepted for publication according to procedures established and overseen by the Transportation Research Board and approved by the Governing Board of the National Research Council.

The opinions and conclusions expressed or implied in this report are those of the researchers who performed the research and are not necessarily those of the Transportation Research Board, the National Research Council, or the program sponsors.

The Transportation Research Board of the National Academies, the National Research Council, and the sponsors of the National Cooperative Freight Research Program do not endorse products or manufacturers. Trade or manufacturers' names appear herein solely because they are considered essential to the object of the report.

Published reports of the

NATIONAL COOPERATIVE FREIGHT RESEARCH PROGRAM

are available from:

Transportation Research Board
Business Office
500 Fifth Street, NW
Washington, DC 20001

and can be ordered through the Internet at:

http://www.national-academies.org/trb/bookstore

Printed in the United States of America

Copyright National Academy of Sciences. All rights reserved.

THE NATIONAL ACADEMIES

Advisers to the Nation on Science, Engineering, and Medicine

The **National Academy of Sciences** is a private, nonprofit, self-perpetuating society of distinguished scholars engaged in scientific and engineering research, dedicated to the furtherance of science and technology and to their use for the general welfare. On the authority of the charter granted to it by the Congress in 1863, the Academy has a mandate that requires it to advise the federal government on scientific and technical matters. Dr. Ralph J. Cicerone is president of the National Academy of Sciences.

The **National Academy of Engineering** was established in 1964, under the charter of the National Academy of Sciences, as a parallel organization of outstanding engineers. It is autonomous in its administration and in the selection of its members, sharing with the National Academy of Sciences the responsibility for advising the federal government. The National Academy of Engineering also sponsors engineering programs aimed at meeting national needs, encourages education and research, and recognizes the superior achievements of engineers. Dr. Charles M. Vest is president of the National Academy of Engineering.

The **Institute of Medicine** was established in 1970 by the National Academy of Sciences to secure the services of eminent members of appropriate professions in the examination of policy matters pertaining to the health of the public. The Institute acts under the responsibility given to the National Academy of Sciences by its congressional charter to be an adviser to the federal government and, on its own initiative, to identify issues of medical care, research, and education. Dr. Harvey V. Fineberg is president of the Institute of Medicine.

The **National Research Council** was organized by the National Academy of Sciences in 1916 to associate the broad community of science and technology with the Academy's purposes of furthering knowledge and advising the federal government. Functioning in accordance with general policies determined by the Academy, the Council has become the principal operating agency of both the National Academy of Sciences and the National Academy of Engineering in providing services to the government, the public, and the scientific and engineering communities. The Council is administered jointly by both Academies and the Institute of Medicine. Dr. Ralph J. Cicerone and Dr. Charles M. Vest are chair and vice chair, respectively, of the National Research Council.

The **Transportation Research Board** is one of six major divisions of the National Research Council. The mission of the Transportation Research Board is to provide leadership in transportation innovation and progress through research and information exchange, conducted within a setting that is objective, interdisciplinary, and multimodal. The Board's varied activities annually engage about 7,000 engineers, scientists, and other transportation researchers and practitioners from the public and private sectors and academia, all of whom contribute their expertise in the public interest. The program is supported by state transportation departments, federal agencies including the component administrations of the U.S. Department of Transportation, and other organizations and individuals interested in the development of transportation. **www.TRB.org**

www.national-academies.org

COOPERATIVE RESEARCH PROGRAMS

CRP STAFF FOR NCHRP REPORT 739/NCFRP REPORT 19

Christopher W. Jenks, *Director, Cooperative Research Programs*
Crawford F. Jencks, *Deputy Director, Cooperative Research Programs*
William C. Rogers, *Senior Program Officer*
Charlotte Thomas, *Senior Program Assistant*
Eileen P. Delaney, *Director of Publications*
Maria Sabin Crawford, *Assistant Editor*

NCHRP PROJECT 08-80 PANEL/NCFRP PROJECT 25 PANEL
Field of Transportation Planning—Area of Forecasting

A.N. "Tassos" Perakis, *University of Michigan, Ann Arbor, MI* (Chair)
Thomas W. Brahms, *Institute of Transportation Engineers, Washington, DC*
Carolyn Clevenger, *Metropolitan Transportation Commission - Oakland, Oakland, CA*
Qiang "Wesley" Hong, *Center for Automotive Research (CAR), Ann Arbor, MI*
Bruce Lambert, *Institute for Trade and Transportation Studies, New Orleans, LA*
Douglas MacIvor, *California DOT, Sacramento, CA*
Bruce Xiubin Wang, *Texas A&M University, College Station, TX*
Ronald J. Duych, *RITA Liaison*
Spencer Stevens, *FHWA Liaison*
Jienki Synn, *FHWA Liaison*
Thomas Palmerlee, *TRB Liaison*

AUTHOR ACKNOWLEDGMENTS

The research reported herein was performed under NCHRP Project 08-80/NCFRP Project 25 by the Rensselaer Polytechnic Institute, the University at Albany, and TNO Delft. The Rensselaer Polytechnic Institute was the lead contractor.

Dr. José Holguín-Veras, William H. Hart Professor of Civil and Environmental Engineering at Rensselaer Polytechnic Institute was the Project Director and Principal Investigator. Dr. Catherine Lawson (University at Albany), Dr. Jeff Ban (Rensselaer), and Dr. Lorant Tavasszy (TNO Delft) are the Co-Principal Investigators. Mr. Herbert S. Levinson and Erica Levine Powers, Esq. (J.D., LL.M. Taxation) are project consultants.

Copyright National Academy of Sciences. All rights reserved.

FOREWORD

By William C. Rogers
Staff Officer
Transportation Research Board

NCHRP Report 739/NCFRP Report 19: Freight Trip Generation and Land Use provides a comprehensive discussion of how the freight system, and specifically freight trip generation and land use, relate. The report consolidates available freight trip generation models in an electronic database to assist practitioners interested in using these models; identifies the most appropriate approaches to develop and apply freight trip generation models; and estimates establishment-level freight trip generation models in a number of case studies. The case studies confirm the superiority of economic classification systems over standard land use classification systems as the foundation for estimating freight trip generation.

While travel-demand modeling has a robust process for estimating passenger travel needs based on the traditional four-step travel-demand modeling process, the same cannot be said for freight-demand modeling. Land use-freight relationships represent a central issue for adequately planning infrastructure investments and land use policy and planning; however, the current transportation planning process does not effectively estimate freight activity necessary to assist decisionmakers when making infrastructure investment choices. Increased truck volumes, coupled with increased multimodal operations and changing logistics, have made it more difficult for standard modeling techniques to fully account for the dynamic nature of freight transportation. Often, evaluating the potential freight trip generation from a proposed project depends on assumptions such as traffic generation based on square footage or other gross characteristics such as establishment type or the number of loading docks.

Under NCHRP Project 08-80/NCFRP Project 25, Rensselaer Polytechnic Institute was asked to (1) define categories of commercial and non-commercial land use and their related characteristics and contexts; (2) define the purposes of freight activities and the segments of freight transportation, and discuss how they relate to the land use definitions; (3) discuss changing practices in supply chain management and distribution facilities and describe their impacts on land use patterns; (4) compare freight and passenger trip generation methods and identify their inherent differences and enumerate the reasons why freight should be approached differently; (5) describe available data sets and models currently used or under development to analyze freight and land use relationships, including establishment level estimates, for considering changing freight transportation needs; and (6) describe what is needed to advance the models and the information that the next generation of models needs to take into account, identify new data collection approaches that should be considered, and identify appropriate uses and limitations of forecasting tools and approaches.

Copyright National Academy of Sciences. All rights reserved.

CONTENTS

Copyright National Academy of Sciences. All rights reserved.

Copyright National Academy of Sciences. All rights reserved.

Note: Many of the photographs, figures, and tables in this report have been converted from color to grayscale for printing. The electronic version of the report (posted on the Web at www.trb.org) retains the color versions.

Copyright National Academy of Sciences. All rights reserved.

SUMMARY

Freight Trip Generation and Land Use

The main objective of NCHRP Project 08-80/NCFRP Project 25 was to study the relationship between freight trip generation (FTG) and land use and ". . . to develop a handbook that provides improved freight trip generation rates, or equivalent metrics, for different land use characteristics related to freight facilities and commercial operations to better inform state and local decision-making." As part of that quest, the research: consolidated the available FTG models in an electronic database (available at http://transp.rpi.edu/~NCFRP25/FTG-Database.rar) to assist practitioners interested in using these models; undertook an in depth examination of the key concepts to identify the most appropriate approaches to develop and apply FTG models; and, used data previously collected by the team to estimate establishment-level FTG models for a number of case studies. This process led to the identification of a number of premises considered to be central to the development of FTG models able to satisfy the needs of both transportation planning and traffic impact analyses.

The most important of these premises is the need to make a distinction between FTG, i.e., the generation of vehicle trips, and freight generation (FG), i.e., the generation of the cargo that is transported by the vehicle trips. FG is an expression of economic activity performed at a business establishment by which input materials are processed and transformed generating an output that, in most cases, is transported elsewhere for further processing, storage, distribution, or consumption. FTG, on the other hand, is the result of the logistic decisions concerning how best to transport the FG in terms of shipment size, frequency of deliveries, and the vehicle/mode used. Of great importance is the shipper's ability to change shipment size to minimize total logistic costs, as it allows shippers and carriers to increase the cargo transported (the FG) without proportionally increasing the corresponding FTG. As a result, FTG cannot be universally assumed to be proportional to business size because large establishments could receive larger amounts of cargo without concomitant increases in FTG. This has major implications for FTG modeling, as standard practices implicitly assume proportionality between FTG and business size variables (e.g., square footage, employment).

Another important premise is that the accuracy of FG/FTG analyses depends on a number of key factors: (1) the adequacy of the classification system used to group commercial establishments in a set of standardized classes; (2) the ability of the measure of business size used to capture the intensity of FG/FTG; (3) the validity of the statistical technique used to estimate the model; and, (4) the correctness of the aggregation procedure used to estimate aggregate values (if required). In addition to these FG/FTG specific factors, other basic principles hold true: the better the quality of the data, the better the results; and, that disaggregate models (establishment level) are generally better than aggregate models (zonal level). In order to ensure proper understanding and use of the terms, brief descriptions are provided. A classification system is a systematic way to group individual entities into pre-defined groupings or classes with which they share common features. An example is a simple land

Copyright National Academy of Sciences. All rights reserved.

use classification that considers, for instance, the three basic classes of "residential," "commercial," and "industrial." A measure of business size is a variable that tries to capture the scale of the operation at the establishment level. Examples include the square footage of the establishment as well as the total number of employees working there. The statistical technique is the process used to compute the parameters of the models. Although there is a wide range of approaches that could be used, the research found two techniques to be particularly useful: ordinary least squares (OLS) (regression analysis), and multiple classification analysis (MCA). The aggregation procedure is the technique used to obtain aggregate values of FG/FTG from the establishment level estimates produced by a disaggregate model. This routinely overlooked aspect is at the core of many of the problems reported by practitioners when producing FG/FTG forecasts.

The analyses revealed a number of aspects of great relevance for modeling purposes, including the following:

- **It is important to use land use classification systems that lead to internally homogeneous classes, in terms of the determinants and patterns of FG/FTG activity**. The heart of the issue is that there is a wide range of land use classification systems that exhibit various degrees of ability to capture the FG/FTG propensity of the business establishments in their classes. At one end of the spectrum one could find land use classification systems that only consider aggregate land use classes (e.g., commercial, industrial) are likely to group together a disparate set of economic activities. In such a case, the ability of business size variables, such as square footage, to be predictors of FTG is undermined by the internal heterogeneity of the FTG patterns in the land use class. In essence, the higher the degree of internal homogeneity, the greater the ability of a business size variable to predict FG/FTG. This implies that if land use classes are defined so that they represent a homogenous set of economic activities, the corresponding business size variables would have a better chance of being good predictors of FG and FTG. At the other end, one finds land use classification systems that are based on a rather comprehensive set of formal descriptors that consider all key dimensions. The Land-Based Classification Standards (LBCS), for instance, classifies land use using five dimensions: the activity (taking place at the establishment); the function (type of enterprise being served); structure type (building characteristics); site development character (physical description of the land); and ownership (e.g., public or private). A unique feature of the LBCS is that its activity dimension contains classes that are defined at a fine level of detail. Such a way of characterizing the activity with this strategy is likely to support proper modeling of FG/FTG, as the resulting classes are expected to be relatively internally homogeneous. The same would occur if a formal industry (economic) classification system [e.g., Standard Industrial Codes (SIC) or North-American Industry Classification System, (NAICS)] is used to classify land use, as the underlying classes meet the condition of internal homogeneity.
- **It is important to use, as predictors of FG/FTG, variables that correctly measure the intensity of FG/FTG activity.** The research clearly showed that commonly used variables, such as square footage and employment, have significantly different levels of explanatory power. The reason is related to their inherent ability to capture the intensity of the FG/FTG. As an example, three establishments of exactly the same square footage will produce different amounts of FG and FTG depending on the amount and type of economic activity being performed, and whether or not the establishments are empty, lightly used, or heavily used. Thus, variables such as employment are likely to be better explanatory variables because they are likely to rise and fall in concert with the level of economic activity and FG/FTG. Alternatively, if variables such as square footage are used, they should be complemented with an additional parameter that represents the percent of capacity being

Copyright National Academy of Sciences. All rights reserved.

used (e.g., full production, minimum production). This would help mitigate the lack of ability of square footage to capture the intensity of the FG/FTG activity.

- **It is important to use the aggregation procedure that corresponds to the underlying disaggregate FG/FTG model**. The research conclusively showed that not using the correct aggregation procedure leads to significant errors in the estimation of FG/FTG. Most notably, the research revealed that the widely used process of obtaining aggregate estimates of FTG by multiplying total employment by an FTG rate per employment is only valid if the underlying model is one in which FTG is directly proportional to employment. In all other cases, different aggregation procedures must be used; in cases where the FTG is a constant that does not depend on business size, aggregate estimates must be found by multiplying the number of establishments in that industry segment by the average FTG for the industry segment. Alternatively, if the disaggregate model includes a constant and a term that depends on employment, the correct way to do the aggregation is to multiply the constant by the number of establishments in the industry segment and add the result to the multiplication of the industry segment's total employment by the FTG rate per employee (the model's second term). Not following these procedures could lead to significant estimation errors.

The premises and conjectures discussed herein were tested using cases studies. To this effect, the research used FG/FTG data from: 362 receivers of supplies in Manhattan and Brooklyn, 339 carrier companies in Northern New Jersey and New York, a furniture store chain in Midwestern states, and, supermarkets in the Puget Sound region and Manhattan. In the cases where the data were most complete, the team had access to establishment-level data, including: employment, location, size, revenue, line of business, some trip data (e.g., number of truck trips per day/week, shipment sizes), and land use information. Using the data, the research compared the performance of FG/FTG models based on: (1) Industrial classification systems (i.e., SIC and NAICS); (2) Land use classification systems [i.e., LBCS and New York City Zoning Resolution (NYCZR)]; (3) the statistical technique used (e.g., ordinary least squares, multiple classification analyses); (4) the aggregation procedure used; and (5) the business size variable used as predictors of FG/FTG. The case studies led to the following findings:

- **The case studies confirmed the superiority of economic classification systems over standard land use classification systems**. The research revealed that using economic classification systems as the foundation for the estimation of FG/FTG models is significantly better than using standard land use classification systems such as the NYCZR, or land use classification systems that can be applied nationally such as LBCS. In cases where these standard systems were used, the vast majority of business size variables were found not to be significant. In contrast, when the economic classification systems were used they tended to produce models that were statistically stronger than the ones obtained using the standard land use classification systems. The best results were found when an economic measure of business size, e.g., employment, was used in combination with an economic classification system (i.e., two-digit SIC codes, or three-digit NAICS codes). In fact, the models using the NAICS codes produced better vehicle trip production models, while the SIC models produced better vehicle trip attraction models. It is important to mention that the results concerning the LBCS are not entirely conclusive due to lack of variability in the data, which suggests the need to conduct additional research with a larger dataset. The team would expect that using LBCS will produce better models than using the standard land use classification systems (such as NYCZR) in terms of its ability to support FG/FTG modeling. Moreover, if the activity codes in the LBCS are made

Copyright National Academy of Sciences. All rights reserved.

consistent with economic classification systems (e.g., SIC, NAICS), one could expect even more improvements in performance.

- **The case studies confirmed that proportionality between FTG and business size only happens in a minority of industry segments**. The research revealed that: in 51% of industry segments, the FTG is constant as it does not depend on business size; in 31% of cases, the FTG model is a function of a constant and a rate that multiplies the establishment's employment; and in the remaining 18% of cases, the FTG model is proportional to employment and a constant FTG rate. The fact that the most commonly used approach (the constant FTG rate per employee) is correct in only a minority of cases, should be a concern.
- **The case studies suggest that the models estimated at the establishment level are transferable, though more testing is needed to reach solid conclusions**. As part of the research, the models estimated with New York City data were applied to supermarkets in the Seattle region. The models were found to produce very good estimates of FTG. This is a very encouraging result, though larger testing is needed to reach definitive conclusions.
- **The case studies suggest that the NCHRP Project 08-80/NCFRP Project 25 models outperform both the Institute of Transportation Engineers (ITE), and some industry segments of the Quick Freight Response Manual (QFRM)**. The models were compared to the ones in ITE's Trip Generation Manual, and the Quick Response Freight Manual. The results show that the land use based models estimated in NCHRP Project 08-80/NCFRP Project 25 produce more accurate FTG estimates than the ITE rates. When comparing with the Quick Response Manual, results show that models for most industry sectors have a similar performance, with the exception of models estimated for the "building material" industry, which perform significantly better.
- **The case studies indicated that Multiple Classification Analysis (MCA) performed better than Ordinary Least Squares (OLS) models**. In conducting the case studies, two alternative estimation techniques were used: OLS (regression analysis) and MCA. The results indicate that for those industries with FTG dependent on employment, MCA performs slightly better than OLS. This was the case for both economic and land use classification based models.

Although the work completed has primarily focused on FTG, the findings have significant implications for both freight transportation planning and traffic impact analyses. During the second phase of the project—which will use the Commodity Flow Survey (CFS)—the research will focus on the estimation of FG models. Ultimately, the entire set of findings will be synthesized in a set of guidelines for FG/FTG modeling.

Copyright National Academy of Sciences. All rights reserved.

CHAPTER 1

Introduction

The effective incorporation of freight transportation considerations into the transportation planning process is extremely important because the freight system is a crucial contributor to a vibrant economy, quality of life, and efforts to combat global warming and climate change. The freight transportation system is important because of both its positive and negative contributions to modern life. An efficient freight transportation system is a necessary condition for economic competitiveness, and for realizing the full potential of economic globalization. On the other hand, freight—along with the rest of the transportation sector—produces many negative externalities, which, in turn, generate community opposition to freight activities. These considerations acquire greater significance in light of the major economic currents shaping the 21st Century. The freight system will have to cover a larger geographic area, be more responsive to user needs and expectations, and reduce the impacts of truck traffic, all with fewer resources for expansions in infrastructure capacity. In short, the freight transportation system will need to do more with less. This adds pressure to state transportation agencies and Metropolitan Planning Organizations (MPOs) to balance the conflicting objectives of the stakeholders involved and impacted by freight.

These challenges are compounded by the complexity of freight, and the lack of appropriate freight modeling methodologies. The lack of research and data concerning freight affects all facets of transportation demand analysis: generation of cargo, distribution, mode choice, and traffic assignment. Overall, there is a great need for research to enhance the state of the quantitative aspects of freight generation. A better understanding of the variables driving the generation of freight demand, and their connection to land use, would help provide more accurate demand forecasts and better quantification of the traffic impacts from freight activity.

This final report provides a detailed account of the work conducted by the research team on the different tasks of NCFRP Project 25. This report is organized as follows: Chapter Two focuses on land use definitions, characteristics, classes, and contexts. It provides a comprehensive discussion of various land use classification systems and their suitability to support freight trip generation modeling. These can be categorized into three groups: those using structure type or site descriptor [e.g., ITE (Institute of Transportation Engineers) Manual or Tax Assessor's codes]; those using industry sectors at the establishment level [e.g., SIC (Standard Industrial Classification) or NAICS (North American Industry Classification System)]; and those using land use planning designations [e.g., LBCS (Land-Based Classification Standards) and NYCZR]. Chapter Three discusses the freight system, purposes of freight activity, and freight's relation to land use. It presents both conceptual and empirical aspects that help explain the functioning of the freight system. In addition, the chapter discusses the differences between freight generation (FG) and freight trip generation (FTG). Chapter Four builds on the discussions from previous chapters and describes the relation between FTG and land use. The chapter proposes a modeling strategy for using the industry composition of different land uses to aggregate FTG estimates.

A review of the literature and current practices in FTG modeling are discussed in Chapter Five. In addition, the chapter describes the comprehensive database of FG and FTG models and publications created by the team. This chapter also provides insights about recommended data collection practices and shows a freight/freight trip generation survey designed by the team.

The results from a set of case studies for estimating the factors influencing freight/freight trip generation and its relation to land use are discussed in Chapter Six. The research analyzed a number of case studies: 362 receivers of supplies in Manhattan and Brooklyn; 339 carrier companies in Northern New Jersey and New York; a furniture store chain in Midwestern States; and, supermarkets in the Puget Sound region and Manhattan. In the cases where the data were most

Copyright National Academy of Sciences. All rights reserved.

complete, the team had access to establishment-level data, including: employment; location; size; revenue; line of business; trip data (e.g., number of truck trips per day/week, shipment sizes, frequencies, empty trucks, type of trucks, hours of operations and in some cases, truck origins and destinations); and land use information. Results show the implications and directions resulting from the analyses, and the external validity and transferability of estimated models.

The report introduces a set of comprehensive and practical improvements, discussed in the Innovation Plan, to enhance FTG modeling practices. This discussion is followed by concluding remarks.

Copyright National Academy of Sciences. All rights reserved.

CHAPTER 2

Land Use Characteristics, Classes, and Contexts

There has long been a desire by transportation professionals to understand the relationship between the physical conditions at the locations where trips begin and end (the "land use"), and the trip-making process. Early efforts to gather information on these locations established the need for a systematic methodology for the collection and classification of data elements to facilitate analysis. Land use analyses and classification have been used for many years for planning. Bartholomew (1955), for example, published his "Land Use in American Cities," containing land use data for 97 municipalities over 20 years. Land use classifications were used in many early Metropolitan Transportation Planning studies, including the Detroit Metropolitan Area Traffic Study (DATS), the Mass Transportation Study National Capital Region (MTS), the Chicago Area Transportation Study (CATS), the Pittsburgh Area Transportation Study (PATS), and the Penn-Jersey Transportation Study (P-J), all begun prior to 1960 (Zettle and Caril 1962).

According to Zettle and Caril (1962), the primary method used for assigning land uses required aerial mapping of the entire study area, with field investigators recording land uses, parcel-by-parcel. This information was used to establish "land use" areas, by analysis zones, based on class of activity (e.g., acres of residential use) and intensity of activity (e.g., number of housing units, retail sales). The problem with these data collection practices is that they make it difficult to analyze changes over time because they focus exclusively upon the present purposes of a study in the application of land use classifications (Sparks 1958). At the same time, Chapin (1957) stated that land use classification systems must anticipate the "exact needs" of each application.

This chapter reviews classification strategies for categorizing commercial and non-commercial land uses and their related characteristics. In a seminal monograph published in 1965 by the American Society of Planning Officials (Guttenberg 1993), the notion that there should be a land use classification system to adequately understand the major elements of land use was introduced. This included the observable (caused) factors, and the underlying causative factors. The observable (caused) factors include: adapted spaces (sites); physical framework (facilities); and activity type and activity effect (sight, sound, smell). The underlying causative factors include economic processes (functions) and legal relationships (e.g., ownership). This suggests that it is necessary to consider the attributes of "land use" as a concept that goes far beyond a set of numerical codes. Berke et al. (2006) identified a set of the attributes that should be considered, including: (1) land as functional space devoted to various uses (e.g., urban, rural, residential, commercial, industrial, public); (2) land as a setting for activities (e.g., working, studying, recreating, commuting); (3) land as part of an environmental system (e.g., floodplain, wetland, forest, wildlife habitat); (4) land as real estate exchange commodity to be bought, developed, and sold (e.g., ownership, assessed value, price, development feasibility); (5) land as publicly planned, services, and regulated space (e.g., future land use, density, zoning, infrastructure); and (6) land as a visual feature for orientation and social symbolism (e.g., corridor, node, neighborhood).

In transportation, the authoritative source for assigning categories of commercial and non-commercial "land uses" has been the ITE *Trip Generation Manual,* 8th edition (Institute of Transportation Engineers 2008). The ITE Manual provides trip generation rates for both passenger and freight trips using a single designated coding system to classify "land uses." The underlying assumption—that passenger and freight trips share the same behavioral mechanisms—is a potential concern for associating freight activities with land uses. For more details on the ITE Manual, see Appendix A.

In addition to the ITE Manual, other land use classification strategies with the potential to include freight trips generation include:

- Local real property assessors' tax classifications;
- Local land use planning classification systems:
  - Local land use inventories, zoning maps, and related land use planning processes and products;

Copyright National Academy of Sciences. All rights reserved.

  - The Standard Land Use Coding Manual (SLUCM);
  - The pioneering LBCS developed by the Federal Highway Administration (FHWA), American Planning Association (APA), and other federal agencies.
- Employment categories:
  - SIC codes;
  - NAICS.
- Remote sensing; and
- Activity systems approach using geospatial dynamics and a multi-dimensional programming algorithm.

Tax Assessor's Classification Codes for Real Property

The development of land use classification codes for tax assessment purposes is a function of state government. See, for example, the New York State Constitution, Article XVI, section 2 (1938): "The legislature shall provide for the supervision, review and equalization of assessments for purposes of taxation." See also Wallis (2001, 123–145), for the history of real property taxation in the United States, and a rationale for its evolution as a tax used primarily at the local level, rather than the federal or state level. Tax assessors are empowered to determine the value of real property for local taxing purposes (Wallis 2001, 123–145, 144–145). To facilitate this process, they use real property classification codes. The Tax Assessor's classification code, which is cross-referenced to a parcel of land on a map, is a numerical code that classifies the use of the parcel for real property taxing purposes.

In some states a uniform real property use classification code is applied. For example, the New York State Office of Real Property Services has developed a "simple and uniform" classification system, see, *New York State Assessor's Manual* (New York State Office of Real Property Services 2006, vii). Pursuant to the New York State Constitution, Article XVI section 2 (1938), ". . . the legislature shall provide for the supervision, review and equalization of assessments for purposes of taxation." Massachusetts also has a uniform real property use classification code (Bureau of Local Assessment 2009). The real property tax assessors' land use classification codes used in New York are shown in Table 1. However, uniformity is not universal. According to Fisher (1996) 21 states have more than one class of real estate, with the number of classes varying from 2 to 34. For example, the situation in Minnesota is "so complex that it is difficult to specify the number of classes" (Fisher 1996, 190). In California, designation of classification schema for tax assessment takes place at the county level, in each of 58 counties.

Land Use Planning Classification Systems

"Land Use Planning" is a multi-dimensional discipline derived from the complex inter-relationship of physical planning (space); ecology (existing systems on the land); and human systems of land use (demographics, economic development, industrial, commercial, residential and societal needs, political systems, particularly at sub-Federal level, availability of funding, and law). Land use planning is implemented through the legal system (Blaesser and Weinstein 1989).

For a century, this discipline has been associated with assigning use categories to land areas. Land use inventories are site-specific to the parcel, but land use classifications in zoning maps and ordinances are aggregations, superimposed on land parcels, and assigned to a specific land area on a map.

The practice of land use planning is supported by theoretically based but practically oriented concepts such as "Euclidian Zoning" (separation of uses of land, particularly separating residential from commercial/industrial uses) (Nolon et al. 2008, 156–167); "New Urbanism" (mixed residential/commercial uses, in walkable neighborhoods); "Smart Growth" (increased urban density, infill development on "brownfields" and the protection of exurban "greenfields" for agriculture and open space) (Mandelker et al. 2008, 852–886; Freilich 1999); and "Sustainable Development" (attempt to protect and preserve local employment opportunities, quality of life, natural resources, and the environment) (Duerksen 2008).

Each of these land use planning concepts has been derived from community needs in a historical context, for example, "Euclidian Zoning," which is named for *Village of Euclid v. Ambler Realty Co.* (272 U.S. 365 (1926), the U.S. Supreme Court case that upheld the constitutional validity of zoning, developed in response to late 19th century public health issues (e.g., urban overcrowding and industrial pollution). "New Urbanism" is one response to the downside of suburbanization, including social anomie and sprawl; and "Smart Growth" and "Sustainable Development" attempt to address scarce natural resources and the impact of climate change [e.g., Mandelker et al. (2008, 218–435), Freilich (1999) and Duerksen (2008)]. Although more recent concepts such as New Urbanism have developed in partial reaction to single-use zoning, Euclidian zoning, adopted in a preponderance of states in the course of the 20th century, may provide a framework for understanding economic activities at the local level due to the separation of activities.

From time to time, model land use codes may be published, but there is no uniformity of land use codes or their implementation among the states. Decision-making in land use planning, which is complex, takes place primarily at the local level by elected officials and appointed boards and commissions. It also tends to be driven by political considerations. Since some of these zoning codes have been in existence for about a century (albeit with amendments), the language that regulates land use is so specific that it can be examined for indications of allowable industries, building sizes and heights, and density (e.g., ratio of floor area to site size, number of shipping docks per square foot of built space) (Mandelker et al. 2008, 281–296).

Copyright National Academy of Sciences. All rights reserved.

Table 1. New York's Tax Assessor's classification codes for freight-related land uses.

Type	Category		Sub-Category	
100 AGRICULTURAL	110	Livestock and Products	111	Poultry and Poultry Products: eggs,
			112	Dairy Products: milk, butter and cheese
			113	Cattle, Calves, Hogs
			114	Sheep and Wool
			115	Honey and Beeswax
			116	Other Livestock: donkeys, goats
			117	Horse Farms
	120	Field Crops		
	130	Truck Crops - Mucklands		
	140	Truck Crops - Not		
	150	Orchard Crops	151	Apples, Pears, Peaches, Cherries, etc.
			152	Vineyards
400 COMMERCIAL	420	Dining Establishments	421	Restaurants
			422	Diners and Luncheonettes
			423	Snack Bars, Drive-Ins, Ice Cream Bars
			424	Night Clubs
			425	Bar
			426	Fast Food Franchises
	430	Motor Vehicle Services	431	Auto Dealers - Sales and Service
			433	Auto Body, Tire Shops, Other Related Auto Sales
	440	Storage, Warehouse and Distribution Facilities	441	Fuel Storage and Distribution Facilities
			443	Grain and Feed Elevators, Mixers, Sales Outlets
			444	Lumber Yards, Sawmills
			447	Trucking Terminals
			448	Piers, Wharves, Docks and Related Facilities
			449	Other Storage, Warehouse and Distribution
	450	Retail Services	451	Regional Shopping Centers
			452	Area or Neighborhood Shopping Centers
			453	Large Retail Outlets
			454	Large Retail Food Stores
			455	Dealerships - Sales and Service (other than auto with large sales operation)
	460	Banks and Office Buildings	464	Office Building
700 INDUSTRIAL	710	Manufacturing and Processing	712	High Tech. Manufacturing and Processing
			714	Light Industrial Manufacturing and Processing
			715	Heavy Manufacturing and Processing
	720	Mining and Quarrying		
800 PUBLIC SERVICES	840	Transportation		

Local Land Use Inventories, Zoning Inventories, and Zoning Maps

Making a land use inventory is an initial step for land use planners, using actual observation in a site-specific parcel-by-parcel on-the-ground survey (Berke et al. 2006, 287–473). This inventory can be graphically expressed in a land classification plan (Metropolitan Planning Commission of Nashville and Davidson County 2006).

In the practice of land use planning, the land use zoning map can vary from the local land use inventory map. For example, the land area on a land use zoning map designated for commercial use can be much greater than the actual land area of commercial uses found on the existing land use inventory map. Thus, the land use type "commercial," can be applied in a different manner depending on whether it is a land use classification on a zoning map, or an observed land use on an inventory map.

Copyright National Academy of Sciences. All rights reserved.

Each local jurisdiction has the ability to prescribe what activities are allowed under each zoning designation. In addition, existing uses are often "grandfathered" as non-conforming use while still a functioning business, e.g., a gas station in an area designated as a residential area.

The Standard Land Use Coding Manual (SLUCM)

In the early 1960s, the Urban Renewal Administration, the Bureau of Public Roads, and Barton-Aschman Associates, Inc., were tasked with determining the feasibility of developing a uniform and universally applicable land use classification and coding system (Urban Renewal Administration Housing and Home Finance Agency and Bureau of Public Roads, 1965). Such a system was needed to collect the data to support the federal Urban Planning Assistance (701) Program, and to reimburse state and local planning agencies for conducting comprehensive planning efforts (Jeer 1997). The expectation was that the system would be useful for both small communities (under 50,000) and large communities.

The most important finding from this work was that different characteristics, or dimensions, used to describe land should not be combined into a single classification system—thus, a single code system was not desirable (Urban Renewal Administration Housing and Home Finance Agency and Bureau of Public Roads 1965). Instead, the authors envisioned a set of variables, to be organized under three headings: Parcel (to include data on location, area of parcel, slope, soil type, etc.); Structure (to include type of structure, total floor area, ground floor area, etc.); and Space Use (to include activity, ownership, floor area, nuisance characteristics, number of employees, etc.). From this breakdown, they chose to focus on "activity" within the category of Space Use, as the primary area of need for uniformity in definition.

The purpose of the SLUCM classification of activities was to establish an extensive system suitable for automated data processing. Previously, records of land uses were prepared manually and used locally. Through the use of data processing equipment, large volumes of processing could be accomplished using a uniform coding system. Although the goal was to consider a standard system of identification for one specific characteristic of land use, i.e., the "activity," they found that no rigid system for classifying land use activity was applicable across all communities.

Most prominent from their work was the realization that a primary activity in one community was a miscellaneous activity in another, based on local economic activities and other factors. Even in the face of this finding, the research team was determined to meet its goal of developing a land use activity classification system that would allow for standardization in coding of the data, while remaining flexible in the use of the data (Urban Renewal Administration Housing and Home Finance Agency and Bureau of Public Roads 1965).

The Space Use system that was developed focused on activity, based on nine one-digit categories (2 categories for manufacturing), 67 2-digit, 294 3-digit, and 772 4-digit categories. This hierarchical system allowed for the greatest detail to be associated with activities at the four-digit level, with the ability to become ever more general at the three-, two- and one-digit levels. The SLUCM structure provided flexibility, with the ability for different agencies to establish the level of aggregation appropriate for their needs (Urban Renewal Administration Housing and Home Finance Agency and Bureau of Public Roads 1965). Although there were concerns among agencies about the additional expense associated with collecting four-digit data, as compared to existing local data systems, the additional costs would be justified with the increased flexibility and accessibility for multiple users.

Table 2 shows the freight-related land use classes. As shown in the table, in the developed SLUCM code, freight activities could be associated with: Codes 2 and 3 (manufacturing); Code 4 (transportation, communication, and utilities); Code 5 (trade [retail]), and Code 8 (resource production and extraction).

There were a series of auxiliary codes within the SLUCM structure to add more detail, when necessary. One area of concern, however, was the ability to properly identify these auxiliary land use activities that appear to be located separately from a primary activity, but are functionally linked. For example, it was difficult to differentiate, without an auxiliary code, a warehouse used exclusively by one retailer; or a parking lot used exclusively by a warehousing operation for its employees, rather than the public. In both cases, the activity associated with the warehouse or the parking lot could be misinterpreted without additional information about the retailer or the warehousing operation.

With respect to the number of SLUCM categories, manufacturing produced the largest number, due to the diverse nature of this activity. A much smaller number of manufacturing activities are found in any one community. To make the dataset sufficiently robust for national use, all of the possible categories needed to be included. Warehousing and storage were coded depending on the set of relationships, with a basic code, an auxiliary code, and a combined code. Although by the late 1960s, the federal classification effort provided individual municipalities with SLUCM, and the SLUCM Manual was reprinted in 1972, local use of the system was voluntary (American Planning Association 1994). By the late 1970s, as the focus of land use planning changed from data-intensive long-range planning, to comply with federal programs, to short-term, small-scale projects, primarily oriented towards local activities, there was less reliance on the SLUCM.

Copyright National Academy of Sciences. All rights reserved.

Table 2. SLUCM categories for freight.

Category	Sub-Codes
2 Manufacturing	21 Food and kindred products – manufacturing
	22 Textile mill products manufacturing
	23 Apparel and other finished products made from fabrics, leather, and similar materials – manufacturing
	24 Lumber and wood products (except furniture) – manufacturing
	25 Furniture and fixtures – manufacturing
	26 Paper and allied products - manufacturing
	27 Printing, publishing, and allied industries
	28 Chemicals and allied products - manufacturing
	29 Petroleum refining and related industries
3 Manufacturing (continued)	31 Rubber and miscellaneous plastic products – manufacturing
	32 Stone, clay and glass products – manufacturing
	33 Primary metal industries
	34 Fabricated metal products – manufacturing
	35 Professional, scientific, and controlling instruments; photographic and optical
4 Transportation, communication, and utilities	41 Railroad, rapid rail transit, and street railway transportation
	42 Motor vehicle transportation
	43 Aircraft transportation
	44 Marine craft transportation
5 Trade	51 Wholesale
	52 Retail trade - building materials, hardware, and farm equipment
	53 Retail trade - general merchandise
	54 Retail trade - food
	55 Retail trade - automotive, marine craft, aircraft and accessories
	56 Retail trade - apparel and accessories
	57 Retail trade - furniture, home furnishings, and equipment
8 Resource production and extraction	81 Agriculture
	82 Agricultural related activities
	83 Forestry activities and related services
	84 Fishing activities and related services
	85 Mining activities and related services

Land-Based Classification Standards (LBCS)

In the early 1990s, there was a concern that the SLUCM needed to be updated to reflect changes that had already been recognized through changes in the SIC coding system (a discussion of the SIC system is presented in a latter section of this chapter). The FHWA partnered with the APA to conduct a feasibility study to determine the level of interest in updating the SLUCM, which was at the time the only national-level standardized land use coding manual for local, regional, and state land use planning applications (American Planning Association 1994). The Research Department of the APA (American Planning Association 1994) found that there was a need to revise the SLUCM to:

- Develop an up-to-date and comprehensive list of land uses and a flexible approach to categorizing new land uses in urban, suburban, and rural areas;
- Provide a system of coding land uses to support the needs of the Clean Air Act Amendments of 1990, the Environmental Justice Order, and the Intermodal Surface Transportation Efficiency Act;
- Facilitate data sharing;
- Develop a coding system with accompanying metadata (e.g., the source of the data);
- Facilitate the updating process;
- Enable regional agencies to work effectively and efficiently with land use/land-cover data; and
- Incorporate the geographic information systems (GIS) capabilities for spatial data.

As part of the scope of work for the APA Study, 21 case studies were conducted to illustrate successful coding systems available at the time. From these case studies, findings were made on the classification of coding schemes used by scale, source of data, and classification method (see www.planning.org/lbcs/). An additional part of the APA Study was the collection of 104 examples of land use coding classifications.

Using the findings from the APA Study, in 1996 the APA and six participating federal agencies (including FHWA) initiated the LBCS project, under the leadership of Sanjay Jeer. The first problem that the team faced was trying to define "land use." Historically, in the planning profession, the term "land use" in classification codes included not only land uses

Copyright National Academy of Sciences. All rights reserved.

(undefined) but also, by implication, land cover (e.g., trees, bushy plants) and land rights (e.g., ownership). In fact, when some agencies used the term "land uses" in policy discussions (e.g., environmental concerns) they tended to extend its meaning to include more than physical or functional characteristics. For example, operations conducted for control purposes (e.g., clear cutting forests, draining swamp lands) could be considered new ways of thinking about land use (Amari et al. n.d.). Given the nature of the problem—trying to define the term "land use"—the LBCS project team made the decision to use the term "land-based" to refer to all the concepts encountered (Jeer 1997). This made it possible to broaden the scope to include all types of land uses and land use activities, land cover, and land rights.

The first task for the team was to update the database of land uses with new uses and activities, as described in the 1987 revised SIC categories, all of which had been added since the original 1965 SLUCM. At this time, another major change was underway—the replacement of the SIC program with the NAICS. (Although the complete transition from SIC to NAICS was not scheduled until 2009, many of the changes occurred in 1999.)

The LBCS was designed to include concepts beyond the strict coding used in SIC or NAICS, including such land use planning applications as comprehensive plans, zoning ordinances, statutes, court case definitions, and other planning-related materials. The overarching guiding principle for the development of the classification systems was to provide a classification scheme for land-based data that could be shared across jurisdictions, both horizontally and vertically. The system was to be user-oriented: easy to understand and use.

It was a challenge to build such a classification system, consisting of defined and ordered categories, with established relationships between the categories. "[A] land-based classification should contain: categories about land-based information; enough categories to differentiate various characteristics of land-based information; and the identification of relationships between those categories." (Jeer 1997, 14). In addition, the LBCS project team would need to decide whether the variables used in the classification system were considered to be nominal, ordinal, or ratio scales. For example, nominal data describes the use of terms such as residential, commercial, or industrial, which only serve the purpose of identifying a class. Variables such as "single-family" and "duplex" are ordinal because they serve to describe an order for the different values. If categories are determined by some numeric description (e.g., number of units per acre), it is ratio scale, as they could be used in mathematical operations. Another consideration for developing the LBCS classification system was what data model to use: levels of abstraction, followed by generalization, association, and aggregation. Within the data model, classification is the "mapping of several objects to a common class" (Jeer 1997, 15). The team decided that a hierarchical coding scheme should be used, rather than text descriptions, in order to facilitate the collection, organization, and extraction of the data. In a hierarchical classification system, digits are used to build a database that is easy to use for aggregating statistics within the database environment (Jeer 1997, 17).

According to the APA, the LBCS called for the classification of land uses in the following dimensions:

- **Activity** refers to the actual use of land based on its observable characteristics. It describes what actually takes place in physical or observable terms (e.g., farming, shopping, manufacturing).
- **Function** refers to the economic function or type of enterprise using the land. Every land use can be characterized by the type of enterprise it serves. Land use terms, such as agricultural, commercial, and industrial, relate to enterprises. The type of economic function served by the land gets classified in this dimension; it is independent of actual activity on the land [emphasis supplied].
- **Structural character** refers to the type of structure or building on the land. Land use terms embody a structural or building characteristic, which suggests the utility of the space (in a building) or land (when there is no building). Land use terms, such as single-family house, office building, warehouse, hospital building, or highway, also describe structural characteristics. Although many activities and functions are closely associated with certain structures, it is not always so. Many buildings are often adapted for uses other than their original use. This is a potential issue for freight transportation as there are many users of freight, e.g., those in retail and services, who occupy structures not directly associated with an obvious freight-related use.
- **Site development character** refers to the overall physical development character of the land. It describes "what is on the land" in general physical terms. For most land uses, it is simply expressed in terms of whether the site is developed or not. But not all sites without observable development can be treated as undeveloped. Land uses, such as parks and open spaces, which often have a complex mix of activities, functions, and structures, need categories independent of other dimensions.
- **Ownership** refers to the relationship between use and its land rights. Since the function of most land uses is either public or private and not both, distinguishing ownership characteristics seems obvious. However, relying solely on the functional character may obscure such uses as private parks, public theaters, private stadiums, private prisons, and mixed public and private ownership. Moreover, easements and similar legal devices also limit or constrain land use activities and functions.

Copyright National Academy of Sciences. All rights reserved.

The underlying principle of the LBCS model was its flexibility, which was provided by making it easier to adapt to a variety of planning applications, data collection methods, data-sharing and data-integrating methods, and color coding and mapping. It also made it possible to assign new categories for new land uses, to accommodate new methods and technologies for analysis, and to customize the model for local needs without losing the ability to share data. Each of these aspects of LBCS called for applying a variety of standards or conventions to maintain consistency in land use classifications. The available resources can be accessed at www.planning.org/LBCS/, including working papers, case study papers, a standard field testing report, an annotated bibliography, and various online resources, including two Access database "seed" files.

To implement the LBCS, users need to apply a prescribed top-level classification scheme, using the following five data collection fields: LBCSActivity, LBCSFunction, LBCSStructure, LBCSSite, and LBCSOwnership. Each parcel of land is assigned the appropriate code for each of the five fields. The site also provides the color coding standards for application in mapping software (e.g., GIS).

Using the LBCS dimensions (American Planning Association 1994), it is possible to identify categories for each dimension relevant for freight. Tables 3 through 7, specifically address the freight-related activity codes within each of the respective dimensions.

Employment Categories

Some transportation studies have used employment codes as a proxy for "land use." The classification systems are national in scope and are applied to establishments to identify industry sectors. The need for these codes developed over a number of years, going back to the 1930s. There is a long history of continued review and improvement associated with these employment classification codes.

Table 3. Land-based classification standards activity codes for freight.

LBCS Activity - Category	Sub-Codes
2000 Shopping, business, or trade activities	2100 Shopping
	2110 Goods-oriented shopping
	2200 Restaurant-type activity
	2300 Office activities
3000 Plant, factory, or heavy goods storage or handling activities	3110 Primarily plant or factory-type activities
	3120 Primarily goods storage or handling activities
8000 Natural resources-related activities	8100 Farming, tilling, plowing, harvesting, or related activities
	8400 Logging
	8500 Quarrying or stone cutting
	8600 Mining including surface and subsurface strip mining

Table 4. Land-based classification standards function codes for freight.

LBCS Function - Category	Sub-Codes
2000 General sales or services	2100 Retail sales or services
	2110 Automobile sales or service establishment
	2120 Heavy consumer goods sales or services
	2130 Durable consumer goods sales and service
	2140 Consumer goods, other
	2150 Grocery, food, beverage, dairy, etc.
3000 Manufacturing and wholesale trade	3100 Food, textiles, and related products
	3200 Wood, paper, and printing products
	3300 Chemicals, and metals, machinery and electronics
	3400 Miscellaneous manufacturing
	3500 Wholesale trade establishment
	3600 Warehouse and storage services
4000 Transportation, communication, information, and utilities	4100 Transportation services
	4110 Air Transportation
	4120 Rail Transportation
	4140 Truck and freight transportation services
	4150 Marine and water transportation
8000 Mining and extraction establishments	
9000 Agriculture, forestry, fishing and hunting	

Copyright National Academy of Sciences. All rights reserved.

Table 5. Land-based classification standards structure codes for freight.

LBCS Structure - Category	Sub-Codes
2000 Commercial buildings and other specialized structures	2100 Office or bank building
	2200 Store or shop building
	2500 Mall, shopping centers, or collection of shops
	2600 Industrial buildings and structures
	2700 Warehouse or storage facility
5000 Transportation-related facilities	5100 Linear or network feature
	5500 Water transportation or marine related
	5600 Air and space transportation facility
	5700 Railroad facility
8000 Sheds, farm buildings, or agricultural facilities	

Table 6. Land-based classification standards site codes for freight.

LBCS Site - Category	Sub-Codes
3000 Developed site - crops, grazing, forestry, etc.	
6000 Developed site - with buildings	

Table 7. Land-based classification standards ownership codes for freight.

LBCS Ownership - Category	Sub-Codes
1000 No constraints - private ownership	
5200 Port authorities	

Standard Industrial Classification (SIC) Codes

In 1934, in the depths of the Great Depression, there was a need to develop a standardized approach to collecting statistics on industries. According to Pearce (1957), the Standardization of the United States Government Industrial Classification program was originally proposed at an Interdepartmental Conference on Industrial Classification held in 1934. A recommendation to develop continuing committee processes to tackle the problem of establishing an industrial classification of statistical data was then transmitted to the Central Statistical Board. In 1937, the Central Board established an Interdepartmental Committee on Industrial Classification, which first met on June 22, 1937. At this first meeting, the Interagency Committee established a Technical Committee to prepare a proposed standard classification of industries. The importance of developing a uniform set of classifications, which could be used by a variety of agencies, was apparent. Otherwise, one agency might classify an establishment in one industry, and another agency, using its own set of classification codes, might classify the same establishment in a different industry (Pearce 1957). Under these circumstances, it would be impossible to collect and use statistics on industries. The standardization project was designed to help clarify the term "industry" in its broadest sense of all economic activity. The first set of industries to be classified was manufacturing. By June 1938, the Interagency Committee accepted a list of manufacturing industries. To overcome coding issues for non-manufacturing industries, the Committee established a number of subcommittees of experts from various non-manufacturing fields (Pearce 1957). The first complete edition of the SIC manual was a series of volumes. According to Pearce, there was a set of guiding principles for inclusion in the SIC manual. They were the following:

- The classification should conform to the existing structure of American industry;
- The reporting units are the establishments, instead of legal entities/companies;
- Each establishment was to be classified according to its major activity; and
- To be recognized as an industry, each group of establishments must have significance from the standpoint of the number of establishments, number of wage earners, volume of business, employment and payroll fluctuations, and other important economic features.

After the 1939 SIC system had been in use for a "reasonable" period of time, there was a review of the coding system,

Copyright National Academy of Sciences. All rights reserved.

and appropriate revisions were made. The Central Statistical Board transferred the SIC program to the Bureau of Budget, which funded the revision process. Following this review, the first edition of the Manufacturing Industries was published in 1941, followed soon after by the publication in 1942, of the Non-manufacturing Industries (Pearce 1957). In 1945, the Manufacturing Industries manual was reviewed and revised to reflect technological advances and changes in industries. The Non-manufacturing Industries manual was reviewed and revised in 1949. Over time, additional review and revision resulted in the publication of the SIC manual, combining manufacturing and non-manufacturing industries into a single book, published in 1957. In 1967, another review and revision was undertaken. The last review and revision of the SIC was conducted by the Office of Management and Budget (OMB) in 1987 (U.S. Census Bureau 2010c). Early freight studies used the SIC system as a proxy for “land use.” Table 8 includes the SIC codes associated with freight.

North American Industry Classification System (NAICS)

In 1991, the International Conference on the Classification of Economic Activities expressing concern about the SIC system, particularly its poor coverage of the emerging service sector, decided to rethink the classification strategy for industries (NAICS Association n.d.). In 1992, partially in contemplation of the North American Free Trade Agreement (NAFTA, implemented in 1994) the OMB established the Economic Classification Policy Committee (ECPC), chaired by the Bureau of Economic Analysis, which included the U.S. Department of Commerce and the Bureau of Labor Statistics, U.S. Department of Labor. The ECPC and Statistics Canada conducted a review of the 4-digit SIC codes and the 1980 Canadian SIC for conformance to economic concepts (NAICS Association, n.d.). The NAICS procedures were finalized by the OMB, jointly with the U.S. ECPC, Statistics Canada, and Mexico’s Instituto Nacional de Estadística y Geografía. The goal was to provide a high level of comparability in business statistics across North America (U.S. Census Bureau 2010c).

The new NAICS codes identified industries using a 6-digit coding system, as the longer code accommodated a larger number of sectors and more flexibility in designating subsectors. The sixth digit can be used for special designations associated with a country (e.g., United States, Canada, or Mexico).

The NAICS currently in use was last updated in 2007 and is scheduled for updating in 2012. NAICS is the current standard used by all federal statistical agencies to classify business establishments for the purposes of collecting, analyzing, and publishing statistical data (U.S. Census Bureau 2010c). It is applied to individual establishments. NAICS is not a “land use” classification per se, but rather a description of the activity being undertaken by a firm. Table 9 lists NAICS codes associated with freight.

Remote Sensing for Diagnostic Land Use Applications

Remote sensing uses sensors to measure the amount of electromagnetic energy leaving an object or geographic area from a distance. This emitted energy is used as a surrogate for the actual properties under investigation. The technique extracts valuable information from the data transmitted, using mathematically and statistically based algorithms. The electromagnetic energy measurements are converted using visual and digital image processing techniques. Remote sensing integrates other geographic information sciences, including GIS, cartography and surveying (Jensen 2007, 4). If the sensors are passively recording electromagnetic energy, they are considered unobtrusive (Jensen 2007, 7).

Remote sensing devices are programmed to systematically collect data (e.g., a single 9 × 9 inch frame of vertical aerial photography or a matrix, as a raster, of Landsat 5 Thematic Mapper data). In most cases, the data itself is collected by various parties, rather than by the researcher who works on the conversion or interprets the results. While remote sensing can bring a new source of data to researchers, it is also at risk of being oversold because so many things can go wrong with it. For example, the devices used to create the data can become uncalibrated, and as a result, the output will be incorrect, and errors imbedded in the data can propagate, resulting in incorrect interpretations in the analysis.

There is a risk that remote sensing techniques that are considered active systems (e.g., LIDAR, RADAR, SONAR) could influence the data being collected. These systems are considered obtrusive because they emit their own electromagnetic radiation (Jensen 2007, 8). The remote sensing process includes: creation of a statement of the problem; data collection; data-to-information conversion; and information presentation (Jensen 2007, 9).

The United States Geological Survey (USGS) *Land-Use/Land-Cover Classification System* (circa 1976) was designed for the detection of resource-oriented land-cover data rather than land use data (Jensen 2007, 451). The classification was initially developed to include land use data that was visually photo-interpreted, but has also been used for digital multispectral remote sensing classification studies (Jensen 2007, 451). According to Jensen (2007, 451), the USGS *Land-Use/Land-Cover Classification System,* although not originally intended for urban applications, was used in urban land use studies by “embellishing” the classification system with detailed Level III, IV, and V urban class definitions.

The modification concept made it possible to include as many levels as desired, while remaining compatible with all the USGS Level I and UU land use and land-cover data compiled

Copyright National Academy of Sciences. All rights reserved.

Table 8. SIC codes for freight-related sectors.

Code	SIC Title	Code	SIC Title
01	Agricultural Production-Crops		
02	Agricultural Production- Livestock		
10	Metal Mining		
20	Food and Kindred Products	201	Meat Products
		202	Dairy Products
		203	Preserved Fruits and Vegetables
		204	Grain Mill Products
		205	Bakery Products
		206	Sugar and Confectionery Products
		207	Fats and Oils
		208	Beverages
		209	Misc. Foods and Kindred Products
22	Textile Mill Products		
23	Apparel & Other Textile Products		
24	Lumber and Wood Products		
25	Furniture and Fixtures		
26	Paper and Allied Products		
27	Printing and Publishing		
28	Chemicals and Allied Products		
29	Petroleum and Coal Products		
30	Rubber & Misc. Plastics Products		
31	Leather and Leather Products		
32	Stone, Clay, and Glass Products		
33	Primary Metal Industries		
34	Fabricated Metal Products		
35	Industrial Machinery & Equipment		
36	Electronic and Other Electric Equipment		
37	Transportation Equipment		
38	Instruments & Related Products		
39	Misc. Manufacturing Industries		
42	Trucking and Warehousing		
51	Wholesale Trade-Nondurable Goods	511	Paper and Paper Products
		512	Drugs, Proprietaries and Sundries
		513	Apparel, Piece Goods and Notions
		514	Groceries and Related Products
		515	Farm Product Raw Materials
		516	Chemicals and Allied Products
		517	Petroleum and Petroleum Products
		518	Beer, Wine and Distilled Beverages
		519	Misc. Nondurable Goods
52	Building Materials and Garden Supplies		
53	General Mechandise Stores		
54	Food Stores	541	Grocery Stores
		542	Meat & Fish Markets
		544	Candy, Nut and Confectionery Stores
		545	Dairy Product Stores
		546	Retail Bakeries
		549	Misc. Food Stores
55	Automotive Dealers & Service Stations	551	New and Used Car Dealers
		552	Used Car Dealers
		553	Auto and Home Supply Stores
56	Apparel and Accessory Stores		
57	Furniture and Homefurnishings Stores		
58	Eating and Drinking Places		
59	Miscellaneous Retail		

Copyright National Academy of Sciences. All rights reserved.

Table 9. NAICS codes for freight-related sectors.

Code	2007 NAICS U.S. Title	Code	2007 NAICS U.S. Title
11	Agriculture, Forestry, Fishing and Hunting	111	Crop Production
		112	Animal Production
		113	Forestry and Logging
		115	Support Activities for Agriculture and Forestry
21	Mining, Quarrying, and Oil and Gas Extraction	211	Oil and Gas Extraction
		212	Mining (except Oil and Gas)
		213	Support Activities for Mining
31-33	Manufacturing	311	Food Manufacturing
		312	Beverage and Tobacco Product Manufacturing
		313	Textile Mills
		314	Textile Product Mills
		315	Apparel Manufacturing
		321	Wood Product Manufacturing
		322	Paper Manufacturing
		323	Printing and Related Support Activities
		324	Petroleum and Coal Products Manufacturing
		325	Chemical Manufacturing
		326	Plastics and Rubber Products Manufacturing
		327	Nonmetallic Mineral Product Manufacturing
		331	Primary Metal Manufacturing
		332	Fabricated Metal Product Manufacturing
		333	Machinery Manufacturing
		334	Computer and Electronic Product Manufacturing
		335	Electrical Equipment, Appliance, and Component Manufacturing
		336	Transportation Equipment Manufacturing
		337	Furniture and Related Product Manufacturing
		339	Miscellaneous Manufacturing
42	Wholesale Trade	423	Merchant Wholesalers, Durable Goods
		424	Merchant Wholesalers, Nondurable Goods
		425	Wholesale Electronic Markets and Agents and Brokers
44-45	Retail Trade	441	Motor Vehicle and Parts Dealers
		442	Furniture and Home Furnishings Stores
		443	Electronics and Appliance Stores
		444	Building Material and Garden Equipment and Supplies Dealers
		445	Food and Beverage Stores
		446	Health and Personal Care Stores
		447	Gasoline Stations
		448	Clothing and Clothing Accessories Stores
		451	Sporting Goods, Hobby, Book, and Music Stores
		452	General Merchandise Stores
		453	Miscellaneous Store Retailers
		454	Nonstore Retailers
48-49	Transportation and Warehousing	481	Air Transportation
		482	Rail Transportation
		483	Water Transportation
		484	Truck Transportation
		485	Transit and Ground Passenger Transportation
		486	Pipeline Transportation
		488	Support Activities for Transportation
		491	Postal Service
		492	Couriers and Messengers
		493	Warehousing and Storage

Source: http://www.census.gov/cgi-bin/sssd/naics/naicsrch?chart=2007.

Copyright National Academy of Sciences. All rights reserved.

in local jurisdictions (*see* Jensen (2007, 453) for classification levels). According to Jensen (2007), remote sensing is useful for land uses such as department stores (e.g., Walmart, K-Mart) which can be identified, along with their large parking lots; food and drug manufacturing establishments; warehousing; and shipping facilities. Jeer (1997) reported that satellite based remote sensing methods for land use were undergoing rapid changes, as improvements in imaging and scanning technologies made them increasingly feasible. Identification of various industry-related components in an image include: extraction; processing; and fabrication (Jensen 2007, 479–480). They are defined as the following:

- Extraction industries that can be identified, based on diagnostic recognition, include: open-pit sites; normal and oversized equipment; site-based transportation infrastructure; piles of extracted materials; and ponds of waste.
- Processing industries that can be identified using remote sensing techniques include: mechanical processing industries; chemical-processing industries; and heat-processing industries. Fabrication industries can be identified as either heavy or light fabrication.
- Transportation facilities, such as railroads, airports, and water facilities are all identifiable using remote sensing techniques.

It should be mentioned, however, that remote sensing is of limited usefulness to identify land use classes such as those in urban areas, where it is difficult to remotely identify if a building is being used for habitation or for commercial use. These cases require the use of other more direct data gathering techniques. An example of remote sensing land use classes is shown in Table 10.

Table 10. Remote sensing land use classifications.

Land Use/ Land Cover Codes				
01 URBAN AND BUILT-UP LAND				
12	*Commercial, Services And Institutional*			
	121	Commercial Retail		
		1211	Building materials, hardware and farm equipment	
		1212	General merchandise/department store	
		1213	Food/groceries	
		1214	Automotive, marine craft, aircraft and accessories/dealers	
		1215	Furniture, home furnishings and equipment	
		1216	Eating and drinking (restaurants)	
	122	Commercial wholesale		
		1221	Food/sundries/beverages	
		1222	Agricultural products/supplies	
		1223	Lumber/hardware/building supplies/paper	
		1224	Industrial product/chemical/petroleum	
		1225	Motor vehicles/parts/supplies	
13	*Industrial*			
	131	Primary metal production		
	132	Petrochemicals		
	133	Primary wood processing and paper mills		
	134	Stone, clay, glass		
	135	Metal & non metal fabrication		
	136	Food processing		
	137	Mining		
14	*Transportation, Communication and Utilities*			
	141	Air transportation		
	142	Rail transportation		
	143	Water transportation		
15	*Industrial and Commercial Complexes*			
	151	Industrial park		
	152	Office park		
	153	Shopping center/mall		
	159	Other industrial/commercial complexes		
02 AGRICULTURAL LAND				
21	*Cropland and Pasture*			
22	*Orchards, Bust Fruits, Vineyards, and Ornamental Horticulture*			
23	*Confined Feeding Operations*			

Copyright National Academy of Sciences. All rights reserved.

Multi-Dimensional Spatially Flexible Land Use Classification Strategy

Trying to implement a standardized set of land use classification codes has proved to be elusive, and will most likely be expensive and time-consuming. As has been echoed through the various attempts to accomplish a standardized approach, the system needs to flexible, and readily adaptable to numerous users, all of whom have different sets of needs.

After reviewing the various approaches to classification strategies for categorizing land uses, there appears to be no land use single code solution that would be appropriate for understanding FTG. The strategies range from a single code (e.g., ITE Manual, Tax Assessor property classification codes) to a multi-dimensional strategy (e.g., the LBCS concept). The geographic representations for land use range from single-point, firm-level codes (e.g., SIC/NAICS employment codes) to large area land use zoning designations (e.g., General Industrial).

Since land use has a spatial component, regardless of which classification strategy is used, if the information has been digitized, it is possible to use GIS technologies to display it. Thus, in addition to examining the relationships across the data sources in tabular format, it is also possible to assemble the land use data spatially, using GIS. Once the spatial layers are loaded, there are emerging technologies for querying and reassembling this spatial information. While spatial data layers can be used to produce composite maps, GIS is even more useful as a methodology for sorting, reclassifying, linking, joining, querying and understanding the dynamic nature of the data. Using GIS as a platform for reclassifying data provides the appropriate mix of standards and flexibility. Analysts and researchers can use GIS to develop approaches to freight trip generating operations with the most effective and efficient combination of data sources, making all these steps possible through the use of automation. Using a set of algorithms and a set of advanced computer science techniques, an interface that would facilitate the use of existing spatial data could be developed as a web service, or a stand-alone personal computing process.

Emerging Land Use Practice of Interest to Freight Transportation Planning

In recent years, some jurisdictions have developed zoning classifications and/or new land use code applications that may contribute to the identification of freight trip generating areas within a region. Some of these examples are discussed in this section.

Boston, Massachusetts

The City of Boston, Massachusetts, has adopted Article 42D (City of Boston [Massachusetts] Redevelopment Authority 1990 as amended through 2006), establishing a Waterfront Manufacturing District. The zoning code language is designed to protect the activities necessary for a working waterfront, and to preserve particular areas for manufacturing uses and waterfront services. The code language explicitly lists the permitted activities by manufacturing use (e.g., cotton ginning, the manufacturing of food products, fur goods and leather products).

By examining the Boston zoning map and code, it may be possible to understand the range of potential truck trips to be generated from the district as a whole. At the same time, while the zoning code provides dimensions of the possible activities that could produce truck trips, it may not be sufficient to establish activity levels, without additional information from available data (e.g., business licenses) or without requiring new data collection efforts (e.g., a survey of business activities on a periodic basis).

Chicago, Illinois

Planners in Chicago, Illinois, are in the process of preparing a regional freight framework that explicitly recognizes land uses associated with freight through the designation of Planned Manufacturing Districts. Policy Recommendation #22 describes the 15 Planned Manufacturing Districts within the 24 industrial corridors in the Chicago area (Cambridge Systematics Inc., 2010b). The purpose of these districts is to preserve land for industrial development using special zoning designations. In addition, the document discusses findings relevant to the understanding of land use and FTG.

The growth of freight volumes in the Chicago region is directly tied to the overall population and employment growth, changes in the national and global logistics patterns, and the evolution of the region's industry structure (Cambridge Systematics Inc., 2010b, 3-3). Thus, by looking at the economic factors of business type, growth, and location as well as population growth, income, and clustering, with the addition of forecasts, it is possible to understand the relationship between land use and current and future regional freight demand. The framework uses: economic structure, industry logistics patterns, freight infrastructure, commodity/vehicle traffic flows, and organization and public policy, as the key elements to understanding the connections between freight and the overall economic health of the region.

Implicitly within this framework, land use activities are described (e.g., warehousing and distribution industry activities in suburban locations). The document illustrates how intermodal activities impact a community by inducing

Copyright National Academy of Sciences. All rights reserved.

pass-through traffic, not conducive to economic benefits for local communities, which contributes to congestion and pavement deterioration. This suggests the need to establish a land use classification strategy to identify intermodal activities explicitly.

In the regional freight framework plan, the Chicago stakeholders have pointed out the lack of regional coordination with respect to land use and FTG, due to individual municipalities managing their land uses in their own best interests. A more focused planning effort could minimize the cumulative impacts of developments associated with FTG, and provide benefits to shippers and haulers, while at the same time improving the quality of life for local residents.

Portland, Oregon

Planners in Portland, Oregon, have established a new land use designation: Freight Districts (City of Portland [Oregon] Office of Transportation 2006). These districts are determined by the presence of industrial sanctuary zones, including IG1, IG2, and IH. Industrial sanctuary zones are part of the Comprehensive Plan for the city of Portland. The zoning language for the three zones is incorporated in the Zoning Code for the City of Portland (City of Portland [Oregon] Bureau of Planning and Sustainability 2010). These zones provide areas where most industrial uses may locate. Other uses are restricted to prevent potential conflicts and to preserve land for industry. The purpose of the development standards for each zone is to allow new development to be similar in character to existing development, creating more viable and attractive industrial areas.

According to the City of Portland Bureau of Planning and Sustainability (2010):

- **General Industrial** areas generally have smaller lots and a grid block pattern. The area is mostly developed, with sites having high building coverage, and buildings that are usually close to the street. IG1 areas tend to be the city's older industrial areas.
- **General Industrial** areas generally have larger lots and an irregular or large block pattern. The area is less developed, with sites having medium and low building coverage and buildings that are usually set back from the street.
- **Heavy Industrial areas** allow all kinds of industries to locate in the zone, including those not desirable in other zones, due to their objectionable impacts or appearance. The development standards are the minimum necessary to assure safe, functional, efficient, and environmentally sound development.

In addition to the guidance provided by the zoning code, the streets located within a freight district are to be designed to provide local truck circulation and access. In this instance, the transportation facilities are well associated with the land use activities. The use of a freight district designation and the associated truck behaviors should be useful in the determination of freight truck trips.

Seattle, Washington

In Seattle, Washington, the land use planning community and the freight community have a long history of cooperation. For example, in the last decade, efforts have led to the establishment of a freight advisory council (see http://www.cityofseattle.net/Transportation/fmac.htm) and other corridor-level efforts to understand freight issues. The current work on the Puget Sound Regional Council 2040 Plan (Cambridge Systematics Inc., 2010a) explicitly recognizes the relationship between land use and FTG, stating that some types of land uses will rely on a steady stream of trucks to deliver raw materials and pick up manufactured products. This requires an understanding of the cluster patterns of industrial and warehouse land uses that produce a higher volume of truck traffic than any other land use types (Cambridge Systematics Inc. 2010a, 84). This would also be true for areas with high concentrations of retail activity. These clusters would be of value for understanding FTG (Cambridge Systematics Inc. 2010a). The Puget Sound Regional Council 2040 Plan also includes strategies for incorporating freight into the urban fabric, including using zoning to guide new industrial and manufacturing activities to locations within the region that already have adequate freight transportation routes, and to reduce the potential for conflict with communities.

Recommendations in the Puget Sound Regional Council 2040 Plan for land use on a region-wide basis include making an effort to streamline industrial and manufacturing land development into eight designated Manufacturing and Industrial Centers (MICs). This strategy would allow manufacturing and warehousing industries to cluster in areas where the price of land and proximity to a broader supply chain would result in benefits, including less time and money required to transport goods (Cambridge Systematics Inc. 2010a, 137). Such a regional zoning strategy would concentrate freight activities into designated areas, where the clustering of industries should prevent spillover externalities into residential neighborhoods, and increase the potential for understanding freight truck trip generation.

San Francisco, California

In San Francisco, California, a major effort has been underway to understand the economic impacts of freight activities. Studies have recognized the impact of local land use decisions on the goods movement system, particularly the real estate

Copyright National Academy of Sciences. All rights reserved.

industry trend of a shrinking land supply for activities that generate freight truck trips (Hausrath Economics Group and Cambridge Systematics Inc. 2004; Metropolitan Transportation Commission 2009). In addition, these studies concluded that the current desire of urban planners to increase the intensity of development through the use of so-called "Smart Growth" strategies is harmful to goods movement in the San Francisco area.

The San Francisco studies involved the use of a series of mapping exercises to compare existing and planned land uses along a specific set of corridors. In particular, they looked at: locations reserved for seaports and airports as designated in regional agency plans; locations where local plans approved continuing industrial uses; locations where local plans identified a mix of permitted business uses; locations where residential and commercial uses will replace existing industrial uses; and locations with major plans for higher-value uses (e.g., research parks) within or near existing industrial uses. In addition, Priority Development Areas (PDAs), which are locally identified infill development sites, were mapped.

Most important, this information was used to classify the goods movement businesses and industries into tiers. Tier 1 businesses/industries included those where goods movement is very important to operations, e.g., in- and outbound freight trips. Nearly 70% of the corridor businesses/industries fell into this classification. The Tier 2 businesses/industries depend on goods movement but only in a secondary manner. Table 11 (Metropolitan Transportation Commission 2009, 11-8) lists the types of businesses/industries in each tier, providing a new classification strategy for understanding freight truck trips.

Sacramento, California

The Sacramento, California, Council of Governments SACOG Regional Goods Movement Study Phase One Report (SACOG Report) (The Tioga Group et al. 2006) recognized that Smart Growth policies are intended to increase density but have no provisions for street widening to accommodate freight trips. The mixing of uses, including live/work developments, tends to exacerbate the problem by allowing uses

Table 11. San Francisco goods movement intensity designations (Tier 1 and Tier 2).

	Description
Tier 1: Goods Movement Dependent Groups	
Transportation and Related	Air Carriers
	Airpots
	Postal, Parcel, and Express
	Maritime Industries
	Seaports
	Rail Carriers
	Truck Carriers
	Household Goods (HHG) Carriers
	Warehousing
	Truck Rental and Leasing
Manufacturing (excluding high tech manufacturing)	Local Manufacturing
	Local/Regional Manufacturing
	Regional Manufacturing
Wholesale Trade	Local Wholesale
	Local/Regional Wholesale
	Regional Wholesale
Other Industries (oil/gas, waste management)	Pipelines and Refineries
	Fuel Dealers
	Resource Extraction
	Waste Management
Tier 2: Other Goods Movement Groups	
Construction	
High-Tech Manufacturing	Computer and Electronics Manufacturing
	Pharmaceutical and Biotech Manufacturing
Transport / Vehicle Support	Transport Support
	Vehicle Towing
Other Industries (equipment rental, utilities)	Equipment Rental
	Utilities and Telecom
	Agriculture and Husbandry

Copyright National Academy of Sciences. All rights reserved.

with different freight transportation needs in the same development, and even the same building (The Tioga Group et al. 2006). Stakeholders in the Sacramento area were concerned that Smart Growth concepts appear to favor “livability” over functionality, and make no explicit provision for efficient truck access. Thus, the Sacramento area is facing the same kinds of land pressures as San Francisco. As was identified in the San Francisco studies (Hausrath Economics Group and Cambridge Systematics, Inc. 2004; Metropolitan Transportation Commission 2009), when distribution centers are located out of the central industrial areas, it results in the need for increased truck miles to bring the goods to the market centers where population and employment centers are located. This adds increased fuel and operating costs, longer travel times, and increased emissions. It also poses employment challenges. The reason is that if transportation and goods movement industries decline in a region, there are job losses for unskilled or marginally educated workers. “Employment generation (quality and quantity) by use type should be a factor in land use decisions” (The Tioga Group et al. 2006, 204). In addition, the SACOG Report raised the issue that many communities are implementing a form-based zoning approach, which emphasizes the form, character, and shape of buildings and their relationship to streets and public spaces. Unfortunately for freight, it is highly likely that the structural and visual characteristics of typical distribution and logistics facilities may be rated negatively with respect to form, character, and building shape.

The Sacramento Region Blueprint Project, as described in the SACOG Report (The Tioga Group et al. 2006, 205), revisits Smart Growth in an effort to address the needs of a truly comprehensive plan that includes freight. The Sacramento Region Blueprint Project discusses the opportunity for an expansion of the scope of Smart Growth principles to “take advantage of goods movement improvement opportunities in the process of rethinking development patterns; insure that proposed developments and development patterns meet functional as well as aesthetic requirements; and avoid being ‘blindsided’ by goods movement issues late in the development cycle.”

Contexts for Land Use Designations

As mentioned previously, many transportation engineers and transportation planners rely on the “land use” classification codes provided in the ITE Manual, which are primarily assigned to types of structures or sites. Employment codes (e.g., SIC or NAICS) have also been applied as proxies for “land use.” It is difficult to generalize about the contexts of “land use” with respect to freight activities, since these applications differ greatly from those used by land use planners. Table 12 is a matrix using three geographies relevant for land

Table 12. Analysis of rural, suburban and urban contexts.

Geography	Comprehensive Plan	Zoning Designations	Demographics	Employment	Modal Characteristics	Facilities Characteristics	Functional Classifications
Rural	Agricultural	Agricultural	Sparse	Agricultural Extraction	Heavy trucks Light trucks Autos [No transit] Rail	Interstate State routes County roads Bridges Minimal local roads	Principal arterials Minor arterial roads Collector roads Local roads
Suburban	Residential Industrial Commercial	Single Family Residential Light Industrial Heavy industrial Highway Commercial	Low density residential areas Limited clusters of single-family residential units	Manufacturing Retail Service	Autos Light trucks Heavy trucks Some transit Rail	Interstate State routes County Roads Some dense local roads	Principal arterials Minor arterial streets Collector streets Local streets
Urban	Residential Industrial Commercial	Multi-family residential Single-family residential Heavy Industrial Light Industrial Commercial Central Business District	High density in mixed use areas Higher density/ multi-family residential units	Light manufacturing Retail Office Service	Mass transit Auto Light trucks Heavy trucks Rail	Dense local road network Access to Interstate	Principal arterials Minor arterial streets Collector streets Local streets

Copyright National Academy of Sciences. All rights reserved.

use applications: rural, suburban, and urban. These three contexts are organized to illustrate broad classes of land uses applied in land use planning through comprehensive plans; zoning (e.g., agricultural, industrial, and commercial uses); and related factors (including demographics, employment, modal characteristics, facilities characteristics and functional classifications).

Structure Type or Site Descriptor

The ITE Manual generally uses a structure type or site descriptor as a definition of "land use" (e.g., furniture store). This enables transportation engineers to observe the number of trucks entering and leaving a structure or site, and assign a calculated trip rate to like-kind structures. Unlike the Tax Assessor's system previously described, the ITE classification strategy lacks a generally accessible administrative mechanism capable of assigning a specific land use code (e.g., 890, furniture store) to a specific property (e.g., specific street address). Although the calculations of trip rates based on the ITE code can be automated using a spreadsheet, the codes still must be manually assigned to specific addresses, which is time-consuming and expensive.

In addition, the calculated trip rates may not reflect the activities occurring at the specific site, including current occupancy, size of structure, number of employees, and elasticity of demand for output. For example, a furniture store (land use code 890) may be vacant; may have few or many employees; may be a very large or a very small building; and may have a varied customer base. Therefore, there could be a large variation in the consequences of freight activity using only a structure/site descriptor approach.

In comparison, Tax Assessor's codes are produced for all structures and parcels of land and can be assembled in a digital format and joined with other attributes (e.g., percentage of total square footage assigned retail activities, size of structure, structure type, etc.). However, as previously discussed in the Tax Assessor codes section, the codes, which are local, can be very diverse, even within a single state. This would make comparisons across studies on freight trips very difficult in those cases where the underlying processes producing the trips are not related to size, but rather to the operations themselves.

Employment Codes

There are some advantages associated with using employment codes (e.g., SIC and NAICS) as proxies for "land use" with respect to FTG. Employment codes are directly relevant for describing the activities occurring on a site or parcel. The data can be geo-coded, with latitude and longitude provided for electronic mapping of the exact street address of the establishment. The data can be aggregated to the data level of ZIP code, traffic analysis zone, or land use planning zone. These codes can provide a direct understanding of what activity is being conducted within a particular structure or on a parcel, often with additional attributes (e.g., number of employees, value of output). These codes, however, do not indicate the variation of intensity of operations (e.g., whether an establishment is producing at full capacity or has slack capacity), or the level of demand for the output of the establishment.

One disadvantage of using employment codes from government agencies is the explicit limitation placed on using these data, due to confidentiality concerns. The strong restrictions make it difficult to share the data, or even for public agencies to use the data at the parcel level. Although comparable data are available from private sector agencies (e.g., InfoUSA or Dun & Bradstreet), gaining access can be very expensive.

Land Use Zoning Designations and Freight

While many municipalities apply specific land use classifications to specific geographic areas (zones), these terms are often very broad, or idiosyncratic (e.g., "heavy industrial" or "highway commercial"). Although there have been various attempts to establish a national standardized land use classification system (e.g., SLUCM and LBCS), it is unclear the extent to which states and municipalities have adopted or maintained either SLUCM or LBCS.

Recently, there has been an effort to bring freight activities into mainstream planning processes with special districts (e.g., Freight Districts in Portland, Oregon; MICS in Seattle, Washington). These areas can have specific facility requirements (e.g., types of street configurations) to accommodate trucks, and other strategies to reduce conflict with residential development.

Where local land use planning (e.g., zoning) is used to encourage industrial development to locate in specific areas (e.g., in Chicago, Illinois, in "Planned Manufacturing Districts"), the goal is to promote a positive relationship between freight-related land use and economic development. These districts, or freight-oriented zones, are intended to help direct the flow of freight traffic in the most efficient and effective manner within urban areas. The most advanced use of such designations is the emerging Global Freight Village concept, where strict attention is paid to assembling mixes of industries and freight facilities (Weisbrod et al. 2002).

Remote Sensing Land Use Designations

Agricultural activities, found in the areas predominately considered rural, generate freight truck trips from farm sites that can be identified using remote sensing techniques. As previously described, industrial activities in suburban areas

Copyright National Academy of Sciences. All rights reserved.

can also be diagnosed with data processing techniques. Urban areas, especially in dense, complex environments, are more likely to be problematic for application of remote sensing techniques for freight-related land use.

Cross-Walks

To facilitate the use of more than one land use classification coding system, a "cross-walk" or connection is required to link similar elements from one coding system to another. For example, a cross-walk from SIC to NAIC codes has been provided by the Census Bureau (*see* http://www.census.gov/epcd/www/naicstab.htm). It is also possible to reconstitute a cross-walk from the LBCS Function codes to NAICS, using some of the original resources produced for the LBCS project.

A series of cross-walks would make it possible to connect each of the various land use classification codes with any and all of the like-kind codes in the other land use classification schemes. It is also possible to create a cross-walk between establishment codes (e.g., SIC or NAICS) and codes used for commodities (e.g., the Standard Transportation Commodity Group), allowing data on commodities to be linked to all other land use classification codes.

Summary

This section summarizes the findings from the review of various land use classification coding strategies.

There is No One Single "Land Use" Classification System Appropriate for Freight. A review of a series of definitions for "land use" found a variety of non-integrated applications and classification codes currently in use. These "land use" applications and classification codes can be categorized into three groups: those using structure type or site descriptor (e.g., ITE Manual or Tax Assessor's codes); those using industry sectors at the establishment level (e.g., SIC or NAICS); and those using land use planning designations (e.g., local zoning or LBCS).

Recent Interest in Freight Planning Has Created New "Land Use" Designations. A number of urban areas have recently begun to address the relationship between freight activities and land use. Special areas, or districts, are being designated to protect industrial activities and better meet the needs of freight community members. The designations include Freight Districts (Portland, Oregon); Planned Manufacturing Districts (Chicago, Illinois); and MICs (Seattle, Washington).

Cross-Walks and Digital Assembly May Make It Possible to Integrate Land Use Classifications. There are a variety of techniques available for combining datasets, including the use of cross-walks and GIS. It may be possible to combine, reclassify, or even create "new" land use categories that are more appropriate for FTG rates or freight modeling than any one classification system currently in use.

While No Classification System is "Ideal," Several Have Been Used with Limited Success and Some Show Great Promise. Several classification systems can be adapted to meet FTG needs. These include using employment codes, such as the NAICS and SIC, or using the limited set published in the ITE *Trip Generation Manual.* Additional tests need to be made on the feasibility of using local land use codes. Even more importantly, tests need to be made on the use of the LBCS approach, as its extensive land use classification strategy offers several features needed for FTG: flexibility, adaptability, and applicability.

Copyright National Academy of Sciences. All rights reserved.

CHAPTER 3

The Freight System, Its Purposes, and Relations to Land Use

This chapter brings together a succinct characterization of the freight transportation system, its relations to the land use system and to a study of FTG. The chapter discusses three main topics:

- **The freight system.** This section contains a comprehensive description of the freight system and its various components. A unique aspect of the discussion is that it defines and covers the different dimensions needed to fully characterize freight activity (e.g., function performed, modes used, geography, and the nature of the connections among the participating agents).
- **The relationship between the freight system and land use.** This section discusses, using both empirical evidence and theory, the relationship between freight activity and land use. It is important to consider these interactions because both systems influence each other.
- **The differences between passenger trip generation models and FTG models.** This section describes and examines the similarities and differences between passenger and FTG. It also discusses the unique aspects of FTG from the perspective of economic theory and supply chain principles. These disciplines are the ones best positioned to explain the complex dynamics that determine FTG.

It is important to define and explain some key concepts and technical terms that will be used throughout the report. Their consistent and proper use is of paramount importance to studying and understanding FTG. These concepts are:

- **Generation:** In accordance to transportation planning practice (Ortúzar and Willumsen 2001), this refers to the processes that determine productions and attractions of both demand and trips.
- **Demand generation:** These are the processes associated with the needs of passengers and freight to be transported to/from different locations. In the case of passenger transportation, this is measured in units of passenger trips; while in freight, typically, units of weight are used.
- **Vehicle-trip generation:** This refers to the number of vehicle trips required to transport a given amount of demand. It depends on the corresponding modal split, and is typically measured in units of passenger-car-trips, and truck trips.

It follows that FG is the tonnage (or volume) of freight to be transported, while FTG is the number of freight vehicles needed to transport freight. As explained later in this chapter, there are good reasons to be rigorous and consistent when using these terms.

It is also important to define precisely the main focus of the analyses in this document, in terms of modes and vehicle types. This report assumes a primary focus on trucking, as this is the most important mode in terms of economic contributions and market share, and it also has the largest impact on congestion and environmental pollution. A second assumption is that all vehicle-types designed for and primarily used for freight purposes must be considered. This includes all trucks from small vehicles, e.g., pick-up trucks, to the largest tractor trailer truck combinations. The reason for including such a wide range of vehicles is that, while one thinks of a "freight vehicle" as a semi-trailer or a large rigid truck, large trucks are the dominant vehicle only in interstate operations. In urban and suburban operations, the vast majority of freight traffic is associated with small vehicles such as pick-up trucks, delivery vans, etc. For example, in New York City small trucks and delivery vans comprise about 90% of the urban freight traffic. There are also commercial passenger vehicles that are used to transport freight. In Denver, a survey found that 36% of passenger vehicles (autos and sport utility vehicles) registered with commercial license plates reported transporting freight (Holguín-Veras and Patil 2005). The predominance of small vehicles in urban freight clearly suggests the need to consider them when estimating and analyzing FTG; not doing so obviously translates into large estimation errors.

Copyright National Academy of Sciences. All rights reserved.

For that reason, unless explicitly stated, the term "truck" refers to all vehicles designed for and primarily used for freight purposes, irrespective of their size. This definition includes dual use vehicles such as pick-up trucks that are also used for passenger travel, but it leaves out cases such as the passenger vehicles that are used to transport freight, as these represent a small portion of the total.

The Freight System

This section provides a comprehensive description of the freight system. Characterizing the freight system is challenging because of its multifaceted and highly heterogeneous nature. In fact, it is hard to think of any other component of the transportation system that is more varied, exhibits so many fundamentally different behaviors, involves more interacting agents, is so pervasive in modern life, and is so rarely studied than freight. Because of this complexity, it is best to describe the freight system in a systematic fashion by defining the relevant dimensions that could be used to characterize it, and then discussing each of these dimensions in some detail. The multi-dimensional nature of the freight system poses a major challenge to simple land use classification systems because it may not be possible to characterize such complexities by a single metric. A formal characterization requires defining the following:

- **Interacting agents:** This includes shippers, carriers, receivers, warehouses, and end-users.
- **Links between participants:** This includes independent companies and integrated companies.
- **Functions:** This includes long-haul transportation, delivery service, and parcel service.

In this context, a specific operation could be characterized by identifying where it belongs in each of the previously described dimensions. Simply identifying a company as a "for-hire carrier," for instance, does not provide enough information to characterize its operations or to understand its behavior. The following sections discuss the relevant dimensions.

Multiplicity of Economic Agents Involved

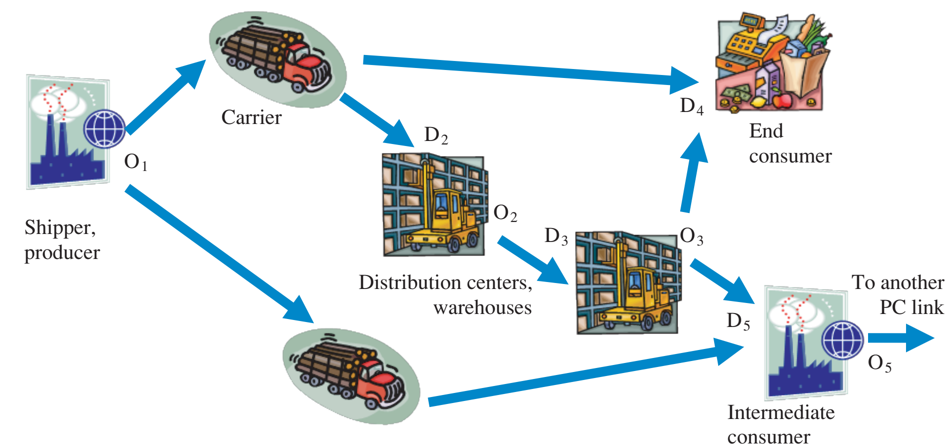
The first level of complexity is related to the many agents that influence the generation of freight. This is an obvious consequence of modern economies that translates into complex logistics and freight systems. As a result, it is useful to envision the freight system as the physical manifestation of the economy, as in most cases, monetary transactions are accompanied by a commodity flow in the opposite direction. In essence, freight activity is the economic activity in motion. As a result, to understand the generation of freight, one must have a basic understanding of the connections among various economic agents.

To decompose the process and facilitate understanding, the concept of a production-consumption (PC) link is useful. A PC link represents the transaction that connects a producer of cargo with the next consumer (which could be the end user or an intermediate one that uses the cargo as an input to another PC link). In essence, a typical supply chain is comprised of many PC links where an economic agent produces/ships freight that other agents process/transform and store, and ultimately deliver to the end/intermediate consumers. Obviously, if the agents are not collocated, transportation has to take place. This, in turn, is what produces the vehicle trips that transportation planners and engineers capture as trip origins (O) and trip destinations (D). In simple supply chains, e.g., a farmer who sells produce to the local market, the corresponding PC pattern is straightforward. In complex supply chains, e.g., in the automobile industry, there could be hundreds of PC links corresponding to the various stages of the production process. The multiplicity of possibilities is overwhelming. A schematic of some of the possibilities is outlined in Figure 1, together with the corresponding trip origins and destinations.

Therefore, to understand freight demand, one needs to study the underlying supply chains that satisfy the needs of the PC links that comprise a production and distribution process. This is because the transportation flows generated as part of these PC connections materialize into freight traffic, e.g., truck trips. The main focus of this research is on locations where the cargo is produced, transformed, stored, or consumed, i.e., the nodes in the transportation network. Understanding the underlying process that determines how much freight is produced or attracted at each land use is the key objective of this project. As a result, the study of the FG and FTG must consider: (1) production sites/shippers; (2) intermediate processing points, including storage; and (3) consumer sites—both end and intermediate.

There are important practical reasons to be comprehensive in the study of FTG. While it is easy to identify production sites, warehouses, trucking companies, and ports as generators of freight and truck trips, the role of consumer oriented businesses as generators of truck trips is frequently overlooked. The need to study FTG by service and retail businesses has long been recognized as a key priority (Fischer and Han 2001). Quite frequently, and particularly in urban areas, small establishments—when taken together—produce more truck trips than any single large generator. As an example, calculations made by the team indicate that the 6,600 restaurants and bars in Manhattan produce more truck traffic than the Port Authority of New York and New Jersey terminals combined.

Copyright National Academy of Sciences. All rights reserved.



Note: The arrows represent transportation flows, O is a trip origin, D is trip destination, and the numbers represent the physical location of the agents in a trip end.

Figure 1. Production-consumption (PC) link.

There are a number of agents relevant to the study of freight transportation: shippers, carriers, receivers, third party logistics, freight forwarders, and warehouses/distribution centers, among others. Their roles are briefly discussed here. As previously described, freight has its origin at supply points (e.g., raw material production sites or areas and manufacturing, distribution, or assembling companies, among others), and the agents who produce and ship freight are typically referred to as *shippers.* These shippers need to send their cargoes to their respective destinations, which requires transportation services that the shippers provide with their own assets, or with the assets of other companies hired by them for that purpose. The companies that transport the goods are known as *carriers.* Carriers are classified as either for-hire carriers, those that provide services to the open market, or private carriers, those that provide transportation services to a parent or a related company. For transportation of the freight, the shippers may contact the carrier companies directly, or they can use the services of intermediary companies, namely the *third party logistics (3PL)* providers, which are companies that provide logistics services for part or all of the shippers' supply chain needs. Typically, 3PLs provide services for integrated operations, including not only transportation but also warehousing and management of the supply chain. Alternatively, the shippers may contact *freight forwarders.* These are a form of third party logistics providers that make use of asset-based carriers for the dispatch of shipments, either by water, ground or air, typically for international shipments. Freight to be transported may have as its destination: a distribution center or warehouse, retailers, wholesale traders, the end consumer, or intermediate consumers. The destination agents act as *receivers* of the cargo. Because of the nature of business relations, the receivers typically set constraints in terms of: delivery times, technology used, and others.

Distribution centers are a special case since they can serve as both receivers *and* shippers of cargo; at these locations, cargo received may be stored, consolidated or split up, or even post-processed or assembled. These processes can impact shipment size, which, in turn, may affect the transportation mode used when shipping to the next destination. Other agents worthy of mention are: *wholesale retailers* which in some occasions may act as distributors (shippers) of the cargo; *intermediate consumers* which may process or conduct transformations to the cargo received and then ship it to the next destination; and finally, the *end consumers.* It is important to note that delivering cargoes to the end consumers may require additional logistical considerations because part of the cargo received, when consumed, may turn into waste that may require additional processing. This is what led to the development of the emerging field of Reverse Logistics. In addition to the agents just described, one can find *intermodal centers* where the transfers between freight modes take place. This includes airports, ports, intermodal rail terminals, and the like, which tend to generate a substantial amount of FTG.

Links Between Participants

An important and frequently overlooked aspect of FTG is the nature of the links between the various agents involved in freight activity. In general terms, the participating agents could be independent companies, or they could be integrated, i.e., part of the same company, and there are other modalities. Figure 2 shows the possibilities for a case involving shippers,

Copyright National Academy of Sciences. All rights reserved.

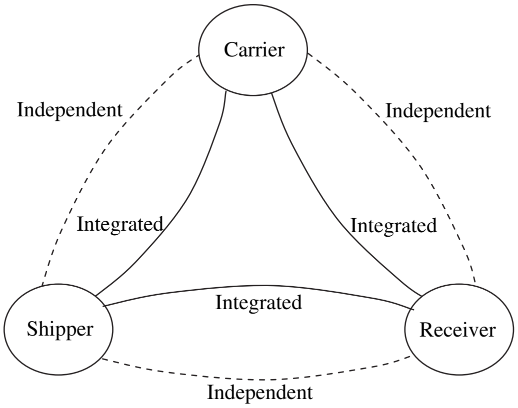


Figure 2. Potential links for a case with a shipper, a carrier, and a receiver.

carriers, and receivers; obviously when the number of agents increases, the number of possibilities increases exponentially.

The nature of the connection between the agents is important because it determines, among other things, the propensity of the agents to engage in cooperative behavior. In the case of integrated operations, the parent company internalizes benefits and costs accrued by the participants. This leads to a decision-making environment in which cooperation and accommodation take place, if it leads to better overall performance. In independent operations—where a company hires another to outsource part of the production and transportation process—the propensity to cooperate is much less as each company tries to maximize its own profits, with little regard to what happens to the other. In this context, a partner in such a transaction is not inclined to cooperate with the other if doing so adversely impacts its profits (regardless of how beneficial the cooperation may be for the other partner). The data on freight behavior confirms these assertions. For instance, private carriers were found to have delivery time windows that were almost double those of for-hire carriers (Holguín-Veras et al. 2005; Holguín-Veras et al. 2006). This suggests that the perceived differences in the behavior of common and private carriers reflect the different constraints that they face, and not because they follow different behavioral rules (the research conducted has failed to find evidence of behavioral differences between common and private carriers).

Partial Views of the Freight System

As a consequence of the many agents involved, no single agent provides a complete picture of FG. Assembling a coherent description of the whole process requires assembling the views provided by the composite parts, i.e., the different agents who may be aware only of those aspects that concern their operation. A summary of the information that each agent is typically aware of is shown in Table 13.

Table 13 shows that producers and shippers of cargo are typically aware of the characteristics of the cargo that they receive and/or ship out. However, they do not know much about what happens once the freight vehicles leave their facilities. Carriers know the details of their operations—including the loaded and empty trips produced—though, quite frequently, they are not aware of the attributes of the cargo they transport. They know who they deliver to, though they do not necessarily know who

Table 13. Partial views of the freight system.

Freight generation:	Shippers / Producers	Carriers	Distribution centers / Warehouses	Consumers of cargo (receivers)	Transportation agencies
Amount of cargo	Yes (1)	Yes (1)	Yes (1)	Yes (2)	No
Number of loaded vehicle-trips	Yes (1)	Yes (1)	Yes (1)	Not always	At key links (no distinction between loaded and empty)
Number of empty vehicle-trips	No	Yes (1)	No	No	
Number, frequency, of deliveries	Yes (1)	Yes (1)	Yes (1)	Yes (2)	No
Commodity type	Yes (1)	Not always	Yes (1)	Yes (2)	Only at some ports of entry
Shipment size	Yes (1)	Yes (1)	Yes (1)	Yes (2)	No
Cargo value	Yes (1)	Not always	Not always	Yes (2)	Only at some ports of entry
Land use patterns	Yes (1)	Yes (1)	Yes (1)	Yes (1)	All

Notes: (1) Only of the cargo that they handle; (2) For all the cargo they receive.

Copyright National Academy of Sciences. All rights reserved.

else is delivering to a particular customer. The consumers of the cargo, i.e., the receivers, know the details of the cargo they receive/ship out, though they do not always know how many vehicle trips have been generated because many of them only observe the number of deliveries (a truck trip could be used to make multiple deliveries). Transportation agencies have an idea about truck traffic in the network and land use patterns. However, in most cases, they know very little about the freight flows in their jurisdictions.

In summary, none of the agents involved in freight have sufficient information to fully describe what happens in the system as a whole. This has important implications for data collection efforts, as most surveys rely on the information gathered from the participants in the freight activity. The fundamental challenge is how to put that information together into a comprehensive picture of FG that is relatively accurate, practical, and conceptually correct. However, from the standpoint of FG and FTG, there should be no doubt that the agents best positioned to provide the most complete view are the consumers and producers of the cargo. This is because they are the ones that know the details of the cargo they receive and/or ship out, and the corresponding delivery frequencies, and shipment sizes. This also implies that establishment data—and the models estimated with them—are the most accurate.

Multiplicity of Metrics to Define and Measure Freight

Freight—and by extension its generation—can be measured by many metrics. These include the value of the cargo, the amount of cargo transported, the vehicle trips produced, and the number of stops and deliveries made. Figure 3 depicts a producer that is sending cargo to nine different customers from its home base (the black circle). In transporting the cargo, the producer makes a tour comprised of six individual trips. The physical origins and destination of the trips are marked by the circles with a number, as well as the one labeled "Base." The locations of the receivers are indicated by the triangles next to the circles. As shown, at stop 1 the carrier makes a delivery to a single customer, at stop 2 the carrier delivers to two customers, and so forth. Upon completion of the deliveries, the carrier returns empty to the home base. Obviously, the establishments that receive these deliveries are likely to receive cargo from other vendors, who are not shown to avoid complicating the figure.

Figure 3 illustrates a number of key points: (1) the origins and destinations of the individual vehicle trips (Base-1, 1-2, 2-3, 3-4, 4-5, and 5-Base) rarely match the direction of the PC relations that link the Base to each of the consumers; they are marked by dashed arrows; (2) a typical receiver does not necessarily know how many vehicle trips are generated, much less how many empty vehicle trips (this is known only to the carrier); and (3) the flow of empty vehicle trips typically runs counter to the commodity flows. The empty trips are important to consider because they could represent sizable portions of the total freight traffic. The data show that, as a percentage of total truck traffic, empty vehicle trips typically represent 20% in urban areas, 30–40% in interstate freight, and 50% of the directional truck traffic in some corridors. In terms of vehicle-miles, the numbers are equally significant; about 57% of the miles traveled by rigid trucks, and 33% of the miles traveled by semi-trailers are empty (U.S. Census Bureau 2004b). As a result of their importance, not explicitly modeling empty trips leads to significant estimation errors, perhaps as high as 83%, contrasted with errors of 57% considering empty trip models (Holguín-Veras and Thorson 2003a).

Modes and Vehicles Used

The mode refers to the type of transportation technology used to transport cargo, which in turn determines the infrastructure and operational needs. The types of modes include: animal-powered transport, human-powered transport, air transport, water transport, rail transport, and road transport, among others. These types of modes are charac-

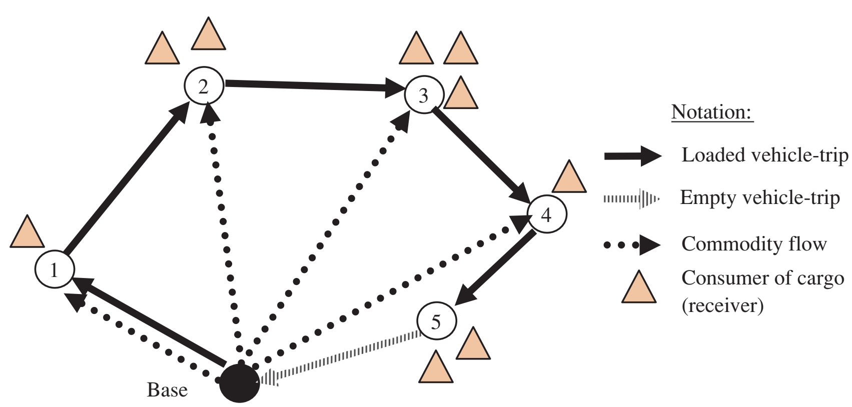
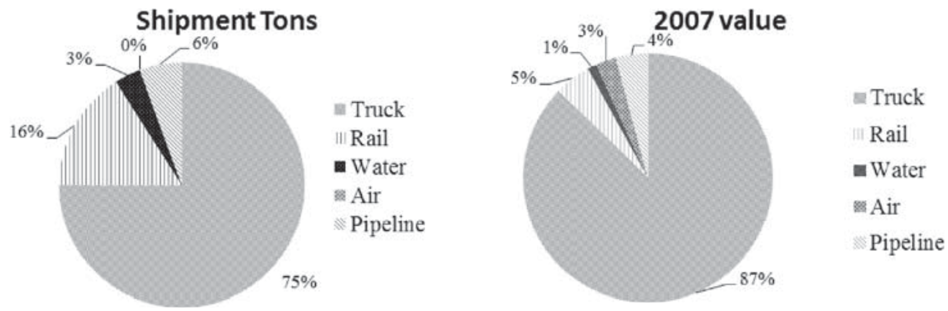


Figure 3. Vehicle trips, commodity flows, and delivery tours.

Copyright National Academy of Sciences. All rights reserved.



Source: Adapted from Bureau of Transportation Statistics (2009).

Figure 4. Breakdown of shipments by mode used.

terized by the infrastructure and initial investment required, vehicles and containers, type of propulsion systems, operational costs, and capacities and speeds, among other factors. In the United States, according to the 2007 Commodity Flow Survey, 93% of the tonnage (representing 81.6% of the value) is transported by a single mode (i.e., truck, rail, water, air, and pipeline). Figure 4 shows the breakdown of freight tonnage by truck, rail, water, air, and pipeline for these modes. The remainder is transported using multimodal combinations.

As shown in Figure 4, truck is the mode with the largest market share; 75% of commodities were transported by trucks in 2007. There are emerging trends in terms of resurgence of rail freight (including extensive use of trailer-on-flat cars and containerization) and the use of ports and rail-truck intermodal centers as major good transfer points. However, the focus of this report is on truck transportation. Table 14 describes the breakdown between for-hire (common) trucks and private trucks. It should be noted that while private truck delivers a larger share of the tonnage, for-hire trucks transport a larger share of the value. This suggests that private trucks are transporting cargoes with values that are lower than those transported by for-hire carriers. In addition to the single modes, there are multimodal freight transportation alternatives that use combinations, such as those presented in Table 15. Among those, the data show that more than 80% of the value transported uses parcel (e.g., packages), United States Postal Service (USPS) or courier, while this group represents only 6% of the tonnage transported by multimodal modes (Bureau of Transportation Statistics 2009).

The complexity of freight transportation is increased by the many commodity types transported around the country. To group the hundreds of thousands of individual products that are transported by the freight system, commodity classification codes are used. The 2007 Commodity Flow Survey (CFS) uses the Standard Classification of Transported Goods (SCTG) codes. The SCTG system has a hierarchical structure and comprises four levels (i.e., 2 to 5-digits) that aggregate the Harmonized System (HS) four or six-digit classes used worldwide for international trade. Each level of the SCTG covers the universe of transported goods, and each category, in each level, is mutually exclusive. In total, about 500 five-digit codes are considered. Table 16 lists the most important commodities; in total they represented 81.9% in value in 2007 (Bureau of Transportation Statistics 2009).

The industries with higher utilization of truck-tractors with single trailers were agricultural, forestry, fishing or hunting, construction and waste management, landscaping, or administrative/support services. The industry with the highest utilization of truck-tractors with single and double trailers corresponds to the for-hire transportation and warehousing businesses (see Tables 17 and 18) (U.S. Census Bureau 2004a).

Level of Geography Involved and Functions Performed

The different functions performed by the various components of the freight transportation system are closely intertwined with the level of geography. In a rather simplified

Table 14. Distribution of trucking company ownership structure.

	Value (million $)	Value %	Tons (thousands)	Tons %
For-hire truck	4,955,700	59%	4,075,136	46%
Private truck	3,380,090	41%	4,703,576	54%
Total	8,335,790		8,778,712	

Source: Adapted from Bureau of Transportation Statistics (2009).

Table 15. Multiple modes of transportation.

Multi modal	Value	Tons
Parcel, USPS or courier	84%	6%
Truck and rail	10%	39%
Truck and water	3%	25%
Rail and water	1%	10%
Other multiple modes	2%	20%

Source: Adapted from Bureau of Transportation Statistics (2009).

Copyright National Academy of Sciences. All rights reserved.

Table 16. Largest commodity groups.

Commodity Type	Value($mil)	Value %	Tons (thous)	Tons %
Mixed freight	7,303,091	8.48%	2,384,804	2.57%
Electronic & other electrical equip & office equip	7,248,316	8.42%	350,589	0.38%
Motorized and other vehicles (including parts)	6,530,511	7.58%	987,405	1.07%
Pharmaceutical products	5,602,658	6.51%	134,107	0.14%
Gasoline and aviation turbine fuel	4,800,101	5.58%	6,900,173	7.44%
Machinery	4,675,732	5.43%	514,479	0.55%
Other prepared foodstuffs and fats and oils	3,756,333	4.36%	3,643,446	3.93%
Base metal in prim. or semifin. forms & in finished shapes	3,711,035	4.31%	2,757,242	2.97%
Plastics and rubber	3,675,205	4.27%	1,366,540	1.47%
Miscellaneous manufactured products	3,481,277	4.04%	705,856	0.76%
Textiles, leather, and articles of textiles or leather	3,451,697	4.01%	354,814	0.38%
Articles of base metal	2,935,810	3.41%	1,024,423	1.11%
Fuel oils	2,715,113	3.15%	4,656,411	5.02%
Chemical products and preparations, nec	2,536,182	2.95%	949,627	1.02%
Meat, fish, seafood, and their preparations	2,192,327	2.55%	775,578	0.84%
Precision instruments and apparatus	2,029,925	2.36%	36,657	0.04%
Coal and petroleum products, nec	1,918,659	2.23%	4,185,478	4.51%
Basic chemicals	1,909,600	2.22%	2,917,137	3.15%
Sub-Total	70,473,572	81.85%	34,644,766	37.37%

Source: Adapted from Bureau of Transportation Statistics (2009).

Table 17. Truck, truck miles, and average miles per truck (2002 VIUS).

Vehicular and operational characteristics	2002 trucks (thousands)	Trucks (%)	2002 truck miles (millions)	2002 average miles / truck (thousands)
BUSINESS				
For-hire transportation or warehousing	1,280.2	1.5	72,272.8	56.5
Vehicle leasing or rental	859.2	1.0	20,024.6	23.3
Agricultural, forestry, fishing, or hunting	2,239.9	2.6	24,120.0	10.8
Mining	177.6	0.2	3,411.5	19.2
Utilities	679.3	0.8	10,244.7	15.1
Construction	4,541.5	5.3	75,906.2	16.7
Manufacturing	782.9	0.9	15,384.5	19.7
Wholesale trade	735.9	0.9	16,963.5	23.1
Retail trade	1,530.5	1.8	27,470.5	17.9
Information services	376.6	0.4	5,622.0	14.9
Waste management, landscaping, admin/support	743.2	0.9	10,709.3	14.4
Arts, entertainment, or recreation services	187.1	0.2	1,784.1	9.5
Accomodation or food services	284.3	0.3	5,816.3	20.5
Other services	2,127.3	2.5	35,776.2	16.8
Personal transportation	65,343.0	76.7	766,639.8	11.7
Not reported	1,308.2	1.5	20,820.7	15.9
Not applicable	1,978.1	2.3	1,761.3	0.9
Total	85,174.8	100.0	1,114,728.0	
VEHICLE SIZE				
Light	79,759.6	93.60	969,104.3	12.2
Medium	1,914.0	2.20	26,255.6	13.7
Light-heavy	910.3	1.10	11,765.7	12.9
Heavy-heavy	2,590.9	3.00	107,602.4	41.5
Total	85,174.8	100.0	1,114,728.0	
BODY TYPE				
Pickup, minivan, other light vans, and sport utility	79,638.4	93.5		
Flatbed, stake, platform, and low boy	1,192.4	1.4		
Van	1,703.5	2		
Service, utility	255.5	0.3		
Van, step, walk-in or multistop	425.9	0.5		
Dump	851.7	1		
Tank for liquids, gases, or dry bulk	340.7	0.4		
Other and not applicable	766.6	0.9		
Total	85,174.8	100.0		

Source: Adapted from U.S. Census Bureau (2004a).

Copyright National Academy of Sciences. All rights reserved.

Table 18. Type of trucks used for industries (2002 VIUS).

Vehicular and operational characteristics	2002 trucks (thousands)	Single-unit trucks and truck-tractors without trailer	Single-unit truck with trailer	Truck-tractor with single trailer	Truck-tractor with double trailer
BUSINESS					
For-hire transportation or warehousing	1,280.2	574.1	21.7	637.9	45.1
Vehicle leasing or rental	859.2	781.8	0.5	76.7	
Agricultural, forestry, fishing, hunting	2,239.9	1,857.5	217.6	156.3	8.5
Mining	177.6	145.9	7.4	23.2	1.1
Utilities	679.3	614.8	56.8	7.5	
Construction	4,541.5	4,208.6	222.9	104.4	5.5
Manufacturing	782.9	706.3	15.6	60.1	0.9
Wholesale trade	735.9	654.8	12.6	66.7	1.8
Retail trade	1,530.5	1,411.8	55.7	62.3	0.7
Information services	376.6	375.1	0.8	0.7	
Waste manag., landscaping, admin/support	743.2	565.0	159	18.8	0.4
Arts, entertainment, or recreation services	187.1	166.6	16.9	3.5	
Accomodation or food services	284.3	261.7	1.1	20.6	0.8
Other services	2,127.3	2,094.4	23.3	9.6	
Personal transportation	65,343.0	64,497.2	845.1	0.7	
Not reported	1,308.2	1,190.4	45.4	71.1	1.3
Not applicable	1,978.1	1,978.0			
Total	85,174.8	82,084.0	1702.4	1320.1	66.1

Source: Adapted from U.S. Census Bureau (2004a).

way, one could identify the following functions and levels of geography:

- **Functions:** urban deliveries; long-haul transportation (trucking, air, maritime); parcel service; and USPS.
- **Levels of geography:** urban; regional; interstate/national; and international.

The key combinations of geography and functions performed are shown in Table 19. As shown, some functions (e.g., urban deliveries, service) are predominantly urban endeavors, while others (e.g., long-haul, parcel service) touch all levels of geography. On a conceptual basis, the freight traffic in urban areas includes the four major vehicle types shown in the table. Urban deliveries, parcel service and USPS, and

Table 19. Key combinations of levels of geography and functions.

	Functions performed			
Level of geography	Urban deliveries	Service related	Parcel service and USPS	Long haul (trucking, rail, air, maritime)
Urban	Predominantly small trucks	Predominantly small trucks	Predominantly small trucks	Transport large volumes of cargo to intermodal sites, distribution centers, or large businesses
Regional	Not applicable	Predominantly small trucks	Predominantly midsize and large trucks	Predominantly midsize and large trucks
Interstate / National	Not applicable	Rarely done	Predominantly large trucks	Predominantly large trucks
International	Not applicable	Rarely done	Predominantly large trucks, air	Predominantly large trucks, rail, air, and maritime

Copyright National Academy of Sciences. All rights reserved.

service trips are typically made using small trucks. In contrast, the long-haul flows arriving to the area by air, water, rail, or trucking, tend to use large capacity freight technology. In cases where these flows arrive at intermodal sites (e.g., airports, rail terminals, ports), the cargo is usually picked up (or delivered in the case of outbound shipments) using large trucks that typically transport the cargo to distribution centers or warehouses in the vicinity of the urban area.

A subject deserving further research is the quantification of service trips, particularly in service areas, and the amount of freight that they transport. This is an increasingly large portion of the commercial vehicle market as modern economies are predominantly based on the service sector, and includes activities such as repair of photocopiers, maintenance of office equipment and computers, and the like.

At the other end of the spectrum, one finds long-haul transportation that typically connects distant manufacturing and consumer sites, distribution centers, and warehouses where the cargo is stored and re-processed, and major intermodal sites where the cargo is transferred to another mode for domestic and international shipping. These operations are very different from urban deliveries as their emphasis is on transporting large volumes of cargo to a relatively small set of destinations. Shipment size increases with shipment distance (Holguín-Veras 2002), which translates into urban areas having smaller shipment sizes than regional, interstate/national, and international transport. The level of geography has a direct impact on the characteristics of the freight operations. A summary of the key features is shown in Table 20.

In general, urban freight operations differ from freight operations in states, regions, or nations. For the urban case, freight movement is performed almost completely by road, since other modes have shown to be inefficient in urban areas (Ogden 1992). Urban deliveries are composed of short-distance movements and multiple stops made on one tour, which normally starts and ends at the warehouse. In most cases, small trucks are the ones used for urban deliveries to consumer oriented establishments (e.g., retail, food) which typically have major constraints on storage space. As a result of the large traffic of small trucks, freight activity produces a significant amount of congestion. There is also a sizable amount of cargo, e.g., bread, that is locally produced and transported using small trucks.

In terms of tour lengths, there are obvious differences. In urban areas, long tours are the norm; in New York City and Denver, the average number of delivery stops is about 5.5 per tour (Holguín-Veras and Patil 2005; Holguín-Veras 2006). In regional, interstate, and international travel, there typically is one delivery stop per tour or two at most.

The percent of empty trips generated is also very different. In urban areas, because of the long tours and better chances of getting cargo for the return trip, the percent of empty trips is typically about 20% (Strauss-Wieder et al. 1989; Holguín-Veras and Thorson 2003a; Holguín-Veras and Thorson 2003b). In regional, interstate, and international travel—where the imbalances of trade tend to be more pronounced—the empty

Table 20. Key features of freight activity by levels of geography.

	Functions performed					
Level of geography	Predominant vehicle/mode	Shipment size	Congestion impacts	Empty trips	Number of deliveries per tour	Nature of clients
Urban	Small trucks	Small, frequent deliveries	High	Typically about 20%	5-6	Predominantly consumer oriented goods
Regional	Midsize and large trucks	Larger shipments	Typically, only an issue at specific bottlenecks	Typically about 30-40%	2-3	Mix of manufacturing and consumer oriented goods
Interstate / National	Midsize/large trucks, rail, and air (high priority goods and parcel)	Large shipments	Typically, only an issue at specific bottlenecks	Typically about 30-40%	1-2	Mix of manufacturing and consumer oriented goods
International	Large trucks, rail, air (high priority goods and parcel), and maritime	Large shipments	Typically, only an issue at specific bottlenecks	Typically about 30-40%	1-2	Mix of manufacturing and consumer oriented goods

Copyright National Academy of Sciences. All rights reserved.

trips could fall between 30% and 40%, and in some corridors up to 50% (Holguín-Veras and Thorson 2003a; Holguín-Veras and Thorson 2003b).

The geographic scales also impact the nature of the planning process. When analyzing the movement of goods or people it is important to characterize the relationships between the spatial constraints and attributes with the origin, destination, quantity, nature, and purpose of the movements. In the same way, when analyzing transportation, interrelations between networks, nodes, and demands, it is also important to consider the factors that affect these components according to their spatial function. An important factor of these relations is their scale, that is, if the transportation system is established over urban/suburban, regional, national, or global geographies (Rodrigue et al. 2006).

Similarly, for planning considerations of geographical scales, differences between the scopes and limitations of each decision appear. According to the Metropolitan Washington Council of Governments and their Transportation Planning Board (National Capital Region Transportation Planning Board 2010), at the ***regional scale***, decisions are made about where and how the city will grow in the long-term. Transportation priorities set at this scale shape future decisions at the city, corridor, and site scale. Regional planning decisions bring together a wide range of stakeholders, from local governments to grassroots advocacy groups. Regional resources for connecting transportation and land use include long-range plans, but also technical resources on addressing issues of concern for the whole region, such as affordable housing. At the ***city or corridor scale***, freight and transit corridors are planned at the scale of a corridor, which may involve multiple local jurisdictions. Cities and counties make decisions about where new development should occur and which areas are in need of revitalization as they prepare land use and transportation plans to guide long- and short-term growth. Transportation and land use decisions at this level involve many stakeholders, from local jurisdictions and transit agencies to neighborhood groups and individual citizens.

Detailed plans for land use and transportation are often made at the ***neighborhood scale***. Station area plans, sector plans, and streetscape plans are all implemented at the neighborhood scale. Decisions about the intensity of new development or the character of key streets impact the neighborhood as a whole. Neighborhood-scale planning can also incorporate planning for community benefits, such as affordable housing. Transportation and land use connections are ultimately implemented at the ***scale of individual sites***. Development connects with surrounding streets, transit stations connect with public spaces and surrounding buildings, and streets create the framework for development.

In addition, and considering that about half of global trade takes place between locations of more than 2,000 miles apart, it is important to consider a broader graphical scale which could be at the ***national or even international level***. Because of the involved geographical scale, most national and international freight movements use several modes, especially when origins and destinations are far apart, and also the inclusion of different types of stakeholders.

Differences Between Passenger, Freight Generation, and Freight Trip Generation

To fully appreciate the differences between passenger and FTG, it is important to make a clear distinction between the generation of demand (e.g., passenger trips, tons) and the generation of traffic (e.g., car trips, truck trips). While most analysts agree that this distinction is of minor importance in passenger transportation, there is a great difference in freight transportation. The reason is related to the degree of correspondence between demand generation and trip generation. In the passenger case, there is a fairly tight correspondence between the amount of trips produced and the associated number of vehicle trips—particularly in areas where transit's share is small—because car occupancies are relatively low, hovering around 1.1–1.2 passengers/car. In contrast, in freight transportation, many businesses could dramatically change their shipment sizes (in some cases by several orders of magnitude) to minimize their total logistic costs. As a result, the tight correspondence that exists in passenger transportation between demand and traffic disappears in the case of freight. Accordingly, one cannot assume proportionality between FG and FTG. In terms of the underlying factors that determine the generation of demand, there are differences as well.

Also, passenger trips are produced mainly at the household level—determined essentially by the socio-economic characteristics of the individual and the household. Freight trips are produced at the farms, factories, and transshipment points, and delivered (attracted) to shops, offices, business areas, etc. They are determined by the establishment characteristics, and by such dynamics as inventory policy and total logistic costs. The key similarities and differences can be summarized as in Table 21.

Table 21 implies that it is imperative to treat the generation of freight demand and the generation of freight vehicle trips as two different concepts. Because businesses have the power to significantly change the sizes of the shipments that they ship out or receive, the FTG is not directly proportional to the FG. As a result, large businesses generate proportionally less FTG than do small businesses, as they handle larger shipment sizes. A second complication is that because of the indivisibility of the vehicle-trip, small businesses that receive small amounts of cargo may generate a disproportionally

Copyright National Academy of Sciences. All rights reserved.

Table 21. Passenger vs. freight trip generation.

Characteristic	Passenger	Freight
Demand generated	Passenger trips	Tons produced or consumed at a given location
Traffic generated	Car trips, bus trips, etc.	Truck-trips, van-trips, etc.
Influencing variables	Income, land use, family structure, car ownership, activity concentration	Economic activity performed, line of business, business size, land use
Correspondence between demand and traffic generated	Very tight, almost one to one in areas where transit share is low	Very loose due to: (1) the role played by the shipment size that leads to a situation where large businesses, while generating large amount of cargo, produce proportionally less traffic because of their large shipment sizes; and (2) the indivisibility of freight-trips, that translates into small businesses generating proportionally large freight trip generation in relation to the demand generated.

high amount of FTG (e.g., delivering one small box requires a truck trip, which is the same needed to transport five boxes of the same product). **These elements lead to a situation in which the FTG depends on business size, with some large companies producing proportionally less FTG than small ones.** Furthermore, the available data for some industry segments show that there is only a weak connection between the number of vendors that deliver goods to establishments and the establishment size. In essence, the average number of vendors is about the same irrespective of size (see section on input required for business operations and Appendix B for some empirical results). As a result, the trip rates for small businesses are typically much larger than the ones for large businesses; trip rates are six times larger in the case of establishments in the Wholesale Trade: Durable Goods industry (see Appendix C for estimates). Yet no such discordance happens in passenger trip generation. This has major implications for modeling because the use of constant trip generation rates is bound to lead to huge errors in the estimation of FTG for certain activities. These issues, together with Table 21, are further discussed in subsequent sections.

Attributes That Influence Freight Trip Generation

As mentioned before, FTG is influenced by factors and attributes somewhat different from those that affect passenger trip generation, and freight generation. The factors and attributes mentioned in the literature include land use (Brogan, 1980; Jack Faucett Associates, 1999), and economic activity at the study area (Cambridge Systematics Inc., 1996). Combinations of company attributes, such as: employment and business area (Iding et al., 2002); industry segment, commodity type transported and employment (Bastida and Holguín-Veras, 2009); total employment, site area, gross floor area, and non-office employment (Bartlett and Newton, 1982) can also be factors. Some studies have produced trip rates for: different types of land use and/or vehicle types (Zavattero and Weseman 1981; Middleton et al. 1986; Tadi and Balbach 1994); special facilities, more specifically ports (Guha and Walton 1993; Wegmann et al. 1995; Al-Deek et al. 2000; Al-Deek 2001; Holguín-Veras et al. 2002; Wagner 2010); and warehouse trip productions (DeVries and Dermisi 2008; Orsini et al. 2009). Table 22 contains a summary of the key results.

In addition, different methodologies have been used to estimate truck trip rates. Garrido (2000) used time series data to develop estimates of productions and attractions. Input-Output (IO) coefficients, data from the 1993 CFS, and average load factors were used by Sorratini (2000) to estimate truck flows for the state of Wisconsin. However, as shown in Table 22, only a subset of these factors has been empirically tested to assess their statistical significance. The latter is important because it is the only scientific way to determine if an attribute could be considered a valid explanatory variable of FTG.

The Role of Shipment Size

The decision about cargo shipment size is without any question one of the most important in freight transportation because it directly impacts both FTG and mode/vehicle choice. Both aspects are discussed in this section.

Impacts on Mode/Vehicle Choice

The process of mode/vehicle choice is one of the most complex aspects of transportation modeling. The discussion here considers the process of vehicle type choice—as well as mode choice—because of their importance to freight transportation planning. The reason is that, since freight vehicles

Copyright National Academy of Sciences. All rights reserved.

Table 22. Summary of findings concerning attributes influencing FTG.

Stratification	Factor	Statistically Tested	Statistically Significant	Source
Land Use	Employment	Yes	Yes	Brogan, 1980
	Building area	Yes	Yes	Tadi and Baldach, 1994
	Establishments	No		Iding et al., 2002
Trip Purpose	Employment	Yes	Yes	Brogan, 1980
Vehicle Type	Employment	Yes	Yes	Zavattero and Weseman, 1981; Brogan, 1980
	Land use	Yes	Yes	Zavattero and Weseman, 1981
	Vehicle Type	No		Middleton et al., 1986
Industry Sector	Employment	Yes	Yes	Iding et al., 2002; Bartlett and Newton, 1982
	Business area	Yes	Yes	Iding et al., 2002; Bartlett and Newton, 1982
	Establishments	No		Iding et al., 2002
	Gross floor area	Yes	Yes	Bartlett and Newton, 1982
	Non-office employ.	Yes	Yes	Bartlett and Newton, 1982
Employment	Commodity type	Yes	Yes	Bastida and Holguín-Veras, 2009
	Type of Business	Yes	Yes	Bastida and Holguín-Veras, 2009
	Industry Segment	Yes	Yes	Bastida and Holguín-Veras, 2009
Number of Truck Drivers	Industry Segment	Yes	Yes	Bastida and Holguín-Veras, 2009
	Type of Business	Yes	Yes	Bastida and Holguín-Veras, 2009
Fleet size	Company SIC	Yes	Yes	Bastida and Holguín-Veras, 2009
Ports	Area	Yes	Yes	Holguín-Veras et al., 2002
	TEUS	Yes	Yes	Holguín-Veras et al., 2002
	Boxes	Yes	Yes	Holguín-Veras et al., 2002
	Daily total vessels	Yes	No	Al-Deek et al., 2000
	Gross tons	Yes	No	Al-Deek et al., 2000
	Gantry crane activity	Yes	Yes	Al-Deek et al., 2000
	Day of the week	Yes	No	Al-Deek et al., 2000
	Imported freight units	Yes	Yes	Al-Deek et al., 2000; Al-Deek, 2001
	Exported freight units	Yes	Yes	Al-Deek et al., 2000; Al-Deek, 2001
	Exported commodity type	Yes	Yes	Al-Deek et al., 2001
	Imported commodity type	Yes	Yes	Al-Deek, 2001
	Exported com. tonnage	Yes	Yes	Al-Deek, 2001
	Imported com. tonnage	Yes	Yes	Al-Deek, 2001
Carrier vs. Receiver, Attraction vs. Production	Employment	Yes	Yes	Bastida and Holguín-Veras, 2009
	Commodity type	Yes	Yes	Bastida and Holguín-Veras, 2009
	Sales	Yes	Yes	Bastida and Holguín-Veras, 2009
	Industry Segment	Yes	Yes	Bastida and Holguín-Veras, 2009

are very heterogeneous, using an average vehicle, e.g., the average truck, leads to major distortions in the analyses. This is because such a generic vehicle unit cannot adequately represent the range of capacities and operational factors of all of those between the smallest and the largest vehicles in the category. At one end, one finds pick-up trucks with typically one ton capacity and at the other end, truck combinations with load capacities that could exceed 50 tons. Obviously, it is not possible to represent such a dissimilar group of vehicles using an "average" class. This is no trivial matter, as the traffic of small freight vehicles is a significant portion of the freight-related traffic, particularly in urban areas. For that reason, the mode/vehicle choice process is one of great import to urban transportation planning, and sustainability efforts.

One of the sources of complexity is that mode/vehicle choice is impacted by the interactions between shippers and carriers, and carriers and receivers, and the decisions they make concerning shipment size and frequency. Although it is frequently assumed that freight mode/vehicle choice is a decision solely made by the carrier—which seems reasonable as it parallels the behavior observed in the passenger case—the reality is that the agent that decides on the shipment size—whether shipper or receiver—also has a major impact on the choice of best mode/vehicle. This has been clearly established by the independent work of two Nobel Prize winners in Economics (Samuelson 1977; McFadden et al. 1986), and confirmed with the assistance of econometric models (Abdelwahab and Sargious 1991;

Copyright National Academy of Sciences. All rights reserved.

Holguín-Veras 2002), analytical formulations (Baumol and Vinoud 1970; Hall 1985) and economic experiments (Holguín-Veras et al. 2009). In the words of Samuelson: ". . . the relevant transportation choice . . . is not simply a choice between modes, but a joint choice of mode and shipment size. In most cases, the shipment size is practically mode determining. . . . Hence, it follows that in freight demand modeling, shipment size and mode choice should always be modeled jointly." (Samuelson 1977, 118–119). In other words, the carrier's decision about mode is conditioned by the decision of shipment size. Adding to the complexity, the decision about the shipment size could be made by either the shipper or the receiver, depending on which one has more market power.

Freight mode/vehicle choice also depends on other factors—more in line with the passenger mode choice practice—such as the economic attributes of the cargo (e.g., commodity type, cargo value, degree of perishability, size), as well as the characteristics of the competing modes/vehicles (e.g., cost, travel time, reliability, probability of cargo damage). Taken together, freight mode choice is an extremely complex subject that is currently poorly understood.

Impacts on Freight Trip Generation

It is rather obvious that, in equality of conditions, business size influences the amount of freight generated as the larger the business, the larger the amount of cargo it is expected to handle. In other words, the larger the business the larger its FG. However, it turns out that the FTG, i.e., the number of vehicle trips generated, is not entirely determined by the amount of freight transported, as FTG also depends on other key aspects such as inventory policy and logistic costs.

Understanding the factors that determine FTG requires the use of inventory theory. A good way to start is the Economic Order Quantity (EOQ) model (Harris, 1915), as it is relatively simple and provides a conceptually solid depiction of the problem. The EOQ model considers a business that needs a certain amount of cargo, and wants to determine the combination of shipment size and delivery frequency that minimizes the total logistic cost (transportation plus inventory costs). Under simple assumptions (Simchi-Levi et al., 2005) the optimal order quantity (shipment size), Q^*, and time between orders, T^*, can be obtained as:

$$Q^* = \sqrt{\frac{2KD}{h}} = \sqrt{\frac{2(\textit{Setup Cost})(\textit{Demand per unit time})}{\textit{Inventory Cost}}} \quad (1)$$

$$T^* = \sqrt{\frac{2K}{h}} = \sqrt{\frac{2(\textit{Setup Cost})}{(\textit{Inventory Cost})(\textit{Demand per unit time})}} \quad (2)$$

From T^*, one could find the optimal frequency f^* as:

$$f^* = \frac{1}{T^*} = \sqrt{\frac{hD}{2K}} = \sqrt{\frac{(\textit{Inventory Cost})(\textit{Demand per unit time})}{2(\textit{Setup Cost})}} \quad (3)$$

The relationships between these variables is summarized in Table 23. The table provides key insights on the elements that an ideal FTG model should capture, though at an appropriate level of detail. The following observations are important:

- The type of economic activity performed by an establishment is very important as it determines the order costs, the amount of cargo (FG, or demand) to be transported, and inventory costs (storage + opportunity cost).
- Businesses with large order costs (setup + transportation), in equality of conditions, tend to receive larger quantities of goods more spaced in time than other businesses.
- Firms handling large volumes of cargo are likely to require, in equality of conditions, larger orders more often than other establishments.
- Establishments with large inventory costs (e.g., limited storage space, handling perishable goods) are going to require frequent shipments of relative small orders.

These variables provide conceptual support for the development of FTG models based on data collected at the establishment level because they are the ones with direct knowledge of the freight deliveries they get/produce.

Equations 1, 2, and 3 clearly show the difference between *FG* and *FTG*. While the freight generation is represented by *D*, the FTG is the product of the number of vehicles to transport Q^* (in most cases, only one vehicle), times the delivery frequency f^*. If the business is receiving goods from multiple vendors, the total FTG would be equal to the summation of the vehicle trips generated by all vendors.

The results also imply that an increase in FG would be accompanied by a less than proportional increase in FTG

Table 23. Relationships among key variables.

Effect:	Optimal order quantity (shipment size) Q*	Delivery frequency f*
Order cost K increase	Increases	Decreases
Demand D increase	Increases	Increases
Inventory cost h increase	Decreases	Increases

Copyright National Academy of Sciences. All rights reserved.

(which is confirmed by the empirical evidence). As an example, consider the case of a business with $K = \$1$/order, $h = \$1$/item, and $D = 1$ item/hour. Applying equations 1 and 3 leads to an optimal shipment size of $Q^* = \sqrt{2}$ items/shipment, and delivery frequency $f^* = 1/\sqrt{2} = 0.707$. Consider now a similar business with exactly the same characteristics (with $K = \$1$/order, $h = \$1$/item) but with a demand that is four times larger ($D = 4$ items/hour). In this case, the optimal shipment size is $Q^* = \sqrt{8} = 2\sqrt{2}$ items/shipment, and the optimal delivery frequency becomes $f^* = \sqrt{2} = 1.41$.

These results show that, contrary to intuition, the larger business does not generate four times the FTG as the small one. Instead, the increase in the FG is handled by smaller increases in both shipment size and delivery frequency. As a result of this, a four-fold increase in FG leads to only double the FTG.

This means that as shipment size increases as the business increases, it may prompt a change in the freight vehicle/modes used towards those with larger capacity. This, in turn, could produce a drop in the FTG. In essence, FTG is intertwined with the process of vehicle/mode choice, in the same way that in passenger transportation, the generation of traffic is determined by the corresponding mode choice process.

Conceptually, the relationship between FG, FTG, and size (in this case measured by employment) generally follows the pattern shown in Figure 5. As shown, larger businesses are expected to generate more cargo than smaller ones. Furthermore, since they are likely to be more productive, large businesses may generate more cargo per employee than small establishments. The FTG is a different matter altogether. In the case of FTG, in proportion to their size, small businesses are expected to generate proportionally more vehicle trips than large ones. This reflects the indivisibility of the vehicle-trip (which forces a minimum number of trips regardless of the amount of cargo), and the effect of increasing shipment sizes that proportionally reduce the FTG for larger establishments. At some point, however, the increases in shipment size lead to a situation in which a change of vehicle/mode is warranted because either the smaller vehicle cannot handle it, or because it is more economical to use a larger vehicle. This produces the pattern illustrated in Figure 5 where the increase in shipment size leads to a vehicle/mode change that produces a drop in the freight traffic.

Number of Inputs Required in Business Operations, Indivisibility of Truck Trips

An important factor reflects the relationship between the number of inputs required by a production process, its relationship to business size, and the indivisibility of vehicle trips. As is widely known, businesses need different inputs to conduct their economic activities. The delivery of these inputs, together with the shipments produced by the firm, determines the FTG. However, the (limited) data available suggest that firms of different sizes in the same line of business tend to require about the same number of inputs, though large establishments are likely to need larger amount of cargo, and thus larger shipments. In a context of economic specialization—where vendors/suppliers specialize in specific segments and are not prone to consolidate shipments with other vendors for fear of losing their customers—most vendors end up sending their vehicles to deliver even the smallest of shipments. As a result, the small amounts of cargo delivered to small businesses require proportionally larger amounts

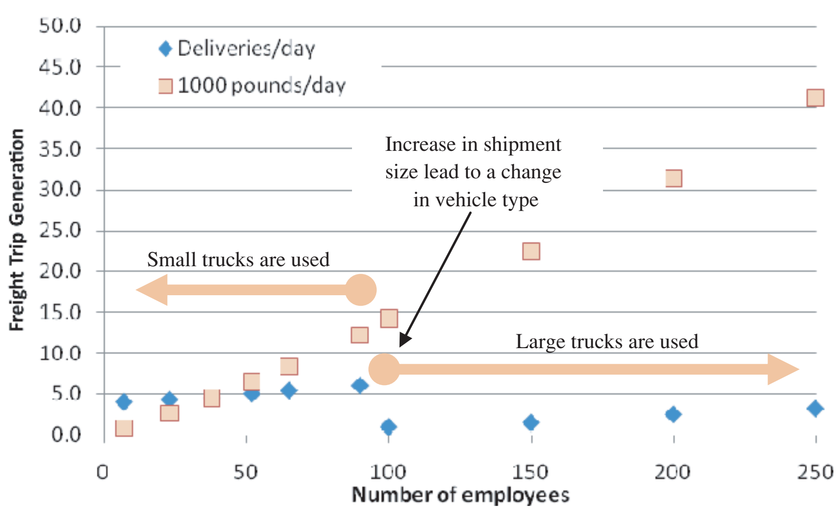


Figure 5. Conceptual relation between freight generation, freight trip generation, and size.

Copyright National Academy of Sciences. All rights reserved.

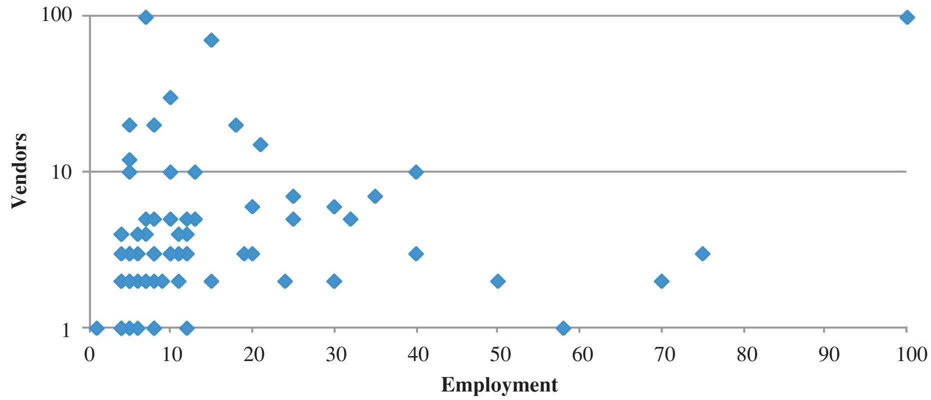


Figure 6. Number of vendors vs. employment (retail trade).

of FTG than those for large establishments that typically use large shipment sizes.

Figure 6 shows a plot of the number of vendors vs. number of employees for a sample of establishments in New York City. As shown, there is no discernible pattern between these two variables. In essence, the number of vendors that deliver products to these establishments is statistically constant (statistical analyses confirmed this result). Additional results for other industry sectors, and the corresponding statistical analyses, are shown in Appendix B.

The ability of large businesses to absorb large shipment sizes along with the relative constancy of the number of inputs required by establishments of different sizes translates into small establishments proportionally generating more FTG than large ones. As a result, it follows that using constant FTG rates as a function of size variables, e.g., employment, may lead to significant errors in the estimation of FTG.

Summary

This section provides a summary of the insights from the analyses reported in this chapter concerning FG and FTG. The analyses lead to the following findings:

1. **The FG at a particular business increases with business size.** To a great extent, this correspondence in growth is to be expected from a competitive market that weeds out inefficient businesses. Under basic conditions of efficiency, the larger the input the larger the output. Furthermore, large businesses are expected to produce proportionally more cargo per unit input than small businesses because, under normal conditions, they should be able to take advantage of scale economies and the like. However, in most economic processes the amount of land available may act as a constraint, not an input, thus limiting the ability of land use variables to explain FTG.
2. **Small businesses tend to produce proportionally more FTG than large ones.** To see why this is the case, consider the case of the inflow of cargo to a business (a relatively similar analysis applies to the outflow). A small business typically needs about *the same number of different inputs* as a large establishment in the same line of business. The fundamental difference is that the small business needs much smaller amounts of cargo. However, since the cargo is likely to be provided by different vendors, and the truck trip is indivisible, small shipments require about the same number of truck trips as larger ones, e.g., transporting one box of a product requires the same number of trips as does five boxes. As a result, in proportion to its size, small businesses produce more FTG than large businesses. In the case of the SIC 50 Wholesale Trade: Durable Goods Industry (see Appendix C), the empirical evidence suggests that FTG rates for small businesses are about six times larger than the ones for large establishments.
3. **Though FG increases with size, FTG often does so at a slower rate.** In real life, businesses schedule deliveries to minimize their total logistic costs. Therefore, they select the combination of shipment sizes and delivery frequencies that minimizes the summation of inventory plus transportation costs. This means that, the transport of more cargo might be accomplished by a dual increase in shipment size, and the corresponding delivery frequency. **As a result of the increase in the shipment size, the increase in the delivery frequency—which is what increases the FTG—is typically smaller than what would have been expected if the shipment size had remained constant.** This explains why large establishments produce proportionally less FTG than smaller ones. The empirical evidence from the literature confirms this assertion. Furthermore, since large shipment sizes can use larger vehicles or more efficient freight modes, it is also likely that the FTG could be smaller than the one for a small establishment (though the vehicles would be larger).

Copyright National Academy of Sciences. All rights reserved.

4. **Both FG and FTG rates depend on business size.** As a consequence of the findings described herein, FG and FTG rates depend on business size. Moreover, when normalized by a business size variable, the FTG rates for small businesses are significantly larger than those for large businesses. As a result of this pattern, if a constant FTG rate is used, the FTG of small businesses would likely be underestimated, and the one for large businesses overestimated.
5. **Variables that influence FTG.** The review of the literature confirms most of the assertions of Findings 1 through 4. The analyses of the sparse data available indicate some industry sectors exhibit FTG that does not increase with business size. In the case of New York City, 7 out of 12 industry sectors exhibit this kind of behavior for freight trip production, and another 11 out of 21 do so for freight trip attraction. The remaining industry sectors exhibit increasing FTG with business size.

   Among those that exhibit variable FTG, the following variables have been found to play a statistically significant role: industry segment, employment, sales, commodity type, and square footage. It should be mentioned that industry segment has only been tested in Europe, as no studies in the United States have tested its significance. However, since employment and industry segment may be correlated, one could expect that in those industry sectors where employment was found to play a role, the industry segment could work as well.

Copyright National Academy of Sciences. All rights reserved.

CHAPTER 4

Freight Trip Generation and Land Use

This chapter discusses the connection between freight activity and land use, building on both empirical evidence and theory. Considering these interactions is important because both systems influence each other. On the one hand, land use patterns could impact FTG patterns as the different activities generate different amounts of freight-related trips; conversely, the freight system could also have a significant impact on land use, which is typically the case with large developments such as distribution centers, terminals, ports, and intermodal centers, which not only influence the freight flows but also the geographic patterns of land use surrounding them.

As clearly established in Chapter 2, the lack of consensus with respect to a definition for the term "land use" blurs the level of clarity needed to accurately describe the connections between freight and "land use." Although there is some evidence of the application of the LBCS for freight, the comprehensiveness of the dimensions (e.g., activity, function, structural characteristics, site development character, and ownership) would be very useful for understanding the relationships between the freight system and land use. For example, in studies that use the ITE Manual land use classifications (i.e., primarily structure-based or site descriptors), it should be possible to map these classifications to the LBCS Structure categories, while studies using employment codes (e.g., SIC or NAIC) could be mapped to the LBCS Function categories, and those using land use planning designations could be mapped to the LBCS Activity categories. Each of these dimensions could have a different impact on FG or FTG, making it essential to reclassify various study outcomes.

In describing the connections between the freight system and land use, it is important to distinguish between two separate aspects: (1) how land use at the establishment level influences FTG; and (2) how freight activity and land use interact with each other at the system level. These effects are shown in Figure 7. Although both aspects are important, since the main emphasis of this project is the impact of land use on FTG, the freight land use connections are not discussed here.

Determining how land use impacts FTG requires resolving and reconciling the difference of opinions between the economic/logistic and the transportation literature. *NCHRP Synthesis 384: Forecasting Metropolitan Commercial and Freight Travel* (2008a) identified as a modeling challenge how truck travel could be modeled without a direct connection to the economic activity that is generating the demand for the movement of the cargo. The economic/logistic literature suggests that FTG is determined by the FG (in itself the output of an economic process), along with a host of interactions concerning shipment size and total logistics costs. Interestingly, this body of literature barely mentions land use as a factor. The reason seems to be that, in most cases, land use is a constraint to the production process, not an input. From the economic/logistic point of view, the input factors that determine FG and FTG include labor, capital, and other intermediate inputs to the process. In essence, the larger the employment or the capital, the larger the FG (while other factors, as discussed, determine the impact on FTG).

The passenger transportation literature is inspired by a different paradigm, dating back to the influential work by Mitchell and Rapkin (1954), which established the impact that urban land use has on passenger traffic generation. From this perspective—which obviously does not explore the economic and logistic aspects of the underlying processes—land use variables such as built area are the ones that explain FTG. Critics point out, however, that such variables cannot measure the magnitude of the use of space, and that other input factors, such as employment, are better explanatory variables.

In contrast, the present research analyses conducted by the team stress the importance of studying FG as well as FTG. The analyses described in this report indicate that business establishments attract and produce cargo FG that translates into freight vehicle trips FTG. The amount and nature of the incoming and outgoing FG depends on the type of business, and its size. In contrast, the FTG depends on the corresponding shipment sizes, and the ability of the carriers to

Copyright National Academy of Sciences. All rights reserved.

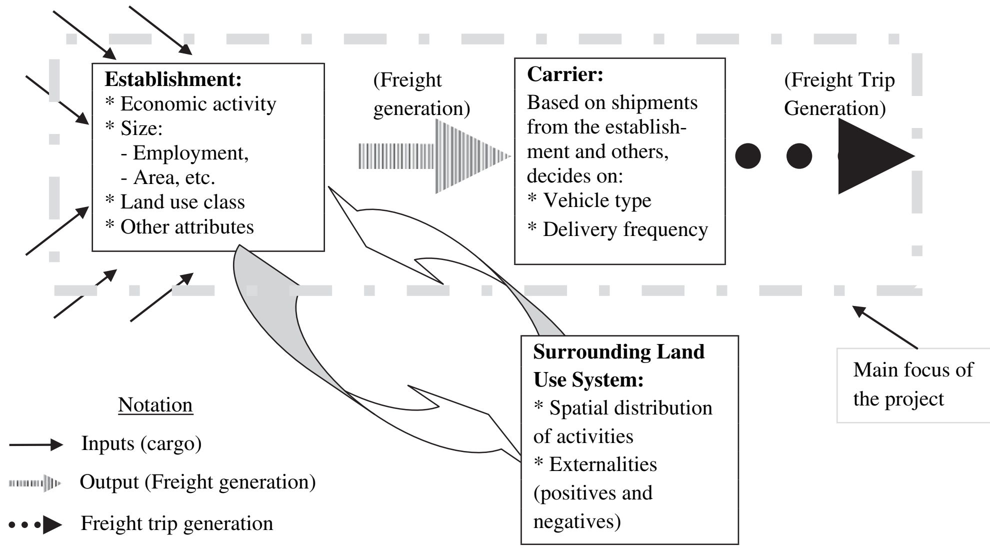


Figure 7. Schematic of connections between freight and land use.

consolidate their shipments (e.g., with the shipments of other establishments). Other factors, such as storage capacity constraints, inventory and transportation costs, etc., play a key role in determining shipment sizes, delivery frequencies, and the amount of inventory.

This suggests that the establishment's land use is, at best, a proxy for the underlying economic activity being conducted. However, in the absence of detailed information about an establishment's economic characteristics, assuming that FTG depends on general characteristics of land use may just be a pragmatic solution. The weakness of this decision is that various land use classes group together economic sectors with fundamentally different FTG patterns. In essence, the adequacy of land use attributes as explanatory variables depends on how well the land use class matches the FTG patterns of the industry segments that have been included. In cases where there is a good match, land use is likely to be a good predictor. In contrast, if a land use class groups together disparate economic activities, it is unlikely to be a good explanatory variable.

To illustrate the divergent ways used to define a land use class, and the implications in terms of FTG analysis and modeling, a subsample of the available disaggregate data (collected from about 800 businesses in the New York City area) was analyzed, and the best FTG models for each two-digit SIC groupings were estimated. Then the team mapped some of the land use definitions reported in the literature (Fisher et. al. 2001). See Table 24. Although the analysis is based on a subsample, it provides some interesting conclusions. The table shows, for each SIC code, the parameters of the FTG models estimated with the New York City data. (Only statistically significant parameters are shown.) Two parameters are displayed: a constant (the number of deliveries per establishment) and the number of deliveries per employee. In some cases, if only the constant is shown, the FTG for that industry sector does not depend on employment level. If only an FTG rate per employee is shown, it means that the FTG increases proportionally to employment level. If both parameters are listed, the implication is that the FTG for that particular industry sector has a minimum value that increases with employment level. As shown in the table, in the case of New York City, the majority of industry sectors have constant FTG. The second largest group has both a constant and a term that increases with employment. The minority of the industry sectors exhibit FTG that increases proportionally to employment.

Key implications from the analyses are as follows:

- There is a lack of uniformity in the definition of land use classes.
- The land use classes typically group together a number of highly heterogeneous industry sectors, with different FTG patterns. See for instance the industry sectors listed under "Retail."
- It is difficult to borrow FTG rates from one location to another.
- In computing an FTG rate as a function of a land use variable such as square footage, the analyst assumes that FTG depends on business size, when in fact this is not the case for a sizable number of industry sectors. (Since for the same line of businesses, employment is likely to be correlated with business area, it is also likely that the widely used square footage only plays a role in industries that exhibit such correlation between FTG and business size.)
- FTG rates based on land use classes that group industry sectors that do not share similar FG and FTG patterns are not likely to do a good job of explaining FTG.

Copyright National Academy of Sciences. All rights reserved.

Table 24. Mapping of SIC and land use definitions found in the literature.

Gr.	Sector	SIC	SIC Description	Del/Est	Del/Emp	Phoenix, AZ	Alameda County, CA	Atlanta, GA	Bangor, ME
1	Agriculture, forestry, and fisheries	1	Agricultural production-crops			I	I	I	I
		2	Agricultural production-livestock and animal specialties			I	I	I	I
		7	Agricultural services			I	I	I	I
		8	Forestry			I	I	I	I
		9	Fishing, hunting, and trapping			I	I	I	I
2	Mineral Industries	10	Metal mining			I	I	I	I
		12	Coal mining			I	I	I	I
		13	Oil and gas extraction			I	I	I	I
		14	Mining / quarrying of nonmetallic minerals, except fuels			I	I	I	I
3	Construc-tion Industries	15	Building constr-general contractors and operative builders		0.132	OB	BS	I	S
		16	Heavy construction other than building construction-contractors	2.467		OB	BS	I	S
		17	Construction-special trade contractors	2.508		OB	BS	I	S
4	Manufacturing	21	Tobacco products	3.377		I	I	I	I
		22	Textile mill products	3.377		I	I	I	I
		23	Apparel and other finished products made from fabrics and similar material	3.778		I	I	I	I
		24	Lumber and wood products, except furniture		0.066	I	I	I	I
		25	Furniture and fixtures	1.434	0.027	I	I	I	I
		26	Paper and allied products	3.377		I	I	I	I
		27	Printing, publishing, and allied industries	3.377		I	I	I	I
		28	Chemicals and allied products	3.377		I	I	I	I
		29	Petroleum refining and related industries	3.377		I	I	I	I
		30	Rubber and miscellaneous plastics products	3.377		I	I	I	I
		31	Leather and leather products	3.377		I	I	I	I
		32	Stone, clay, glass, and concrete products	3.377		I	I	I	I
		33	Primary metal industries	3.377		I	I	I	I
		34	Fabricated metal products, except machinery and transportation equipment	2.875		I	I	I	I
		35	Industrial and commercial machinery and computer equipment	3.377		I	I	I	I
		36	Electronic and other electrical equipment and components, except computer	3.377		I	I	I	I
		37	Transportation equipment	3.377		I	I	I	I
		38	Instruments and related products	3.377		I	I	I	I
		39	Miscellaneous manufacturing industries	3.377		I	I	I	I
5	Transportation, Communication, and Utilities	40	Railroad transportation			OB	BS	I	S
		41	Local/suburban transit/interurban highway passenger transportation			OB	BS	I	S
		42	Motor freight transportation and warehousing			OB	BS	I	S
		43	United states postal service			OB	BS	I	S
		44	Water transportation			OB	BS	I	S
		45	Transportation by air			OB	BS	I	S
		46	Pipelines, except natural gas			OB	BS	I	S
		47	Transportation services			OB	BS	I	S
		48	Communications			OB	BS	I	S
		49	Electric, gas, and sanitary services			OB	BS	I	S

(continued on next page)

Copyright National Academy of Sciences. All rights reserved.

Table 24. (Continued).

Gr.	Sector	SIC	SIC Description	Del/Est	Del/Emp	Phoenix, AZ	Alameda County, CA	Atlanta, GA	Bangor, ME
6	Whole-sale Trade	50	Wholesale trade - durable goods	3.071	0.054	R	R	R	R
		51	Wholesale trade - nondurable goods	1.813	0.074	R	R	R	R
7	Retail Trade	52	Building materials, hardware/garden/mobile home dealers		0.353	R	R	R	R
		53	General merchandise stores	2.899		R	R	R	R
		55	Automotive dealers and gasoline service stations		0.353	R	R	R	R
		56	Apparel and accessory stores	1.314	0.032	R	R	R	R
		57	Home furniture, furnishings, and equipment stores	3.714		R	R	R	R
		59	Miscellaneous retail	2.902		R	R	R	R
8	Food	20	Food and kindred products	1.609	0.010	I	I	I	I
		54	Food stores	2.764	0.011	R	R	R	R
		58	Eating and drinking places	2.017	0.034	R	R	R	R
LAND USE CLASSES USED IN THE MODELING EFFORT:						Office, Retail (R), Industrial (I), Gove-rnment, Households, Other businesses (OB)	Manufacturing (I), Business services (BS), Retail (R), Other (O)	Industrial (I), Retail (R), Office, Population	Retail (R), Industrial/low commercial (I), Services/office/ institutional (S), Household

Note: For some industry segments where not enough data were available, models were estimated for industry group.

These considerations suggest that ensuring a good match between land use classes and the underlying FG and FTG patterns could be accomplished by either one of the following:

- Redesigning FG and FTG modeling so that it could be properly linked to the land use classification system being used at a particular jurisdiction, and/or
- Fostering the use of land use classification systems that are consistent with the underlying patterns of FG and FTG.

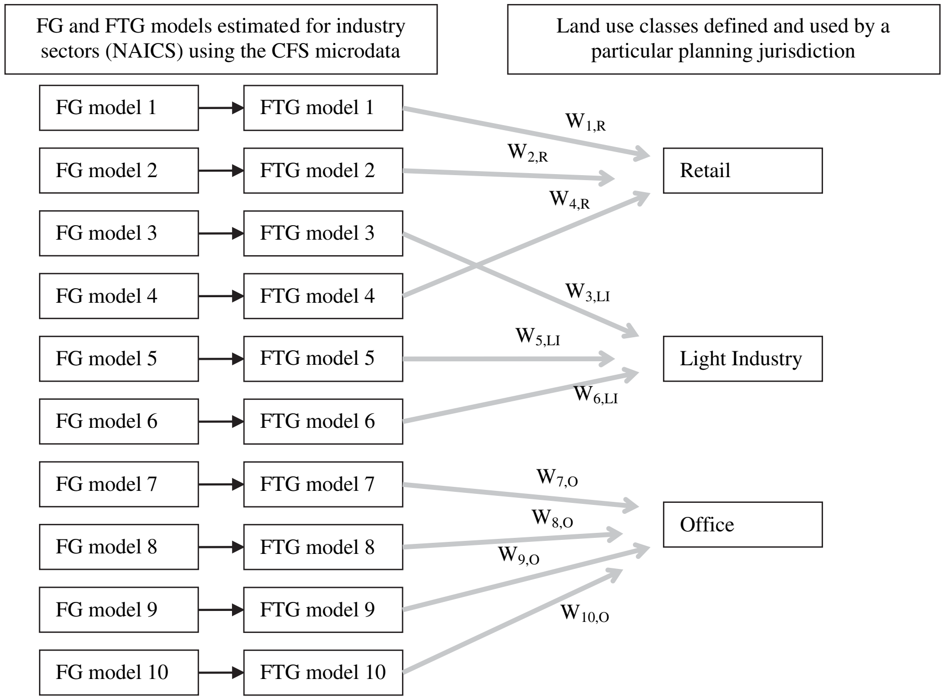
An attractive way to redesign FG and FTG modeling to deal with the challenge associated with the potentially significant number of different definitions of land use is to:

- Estimate FG and FTG models for the various industry sectors captured by the CFS data.
- Develop tools that enable Metropolitan Planning Organizations (MPOs) and State Departments of Transportation (DOTs) **to mix the industry sector FTG models in the proper proportions, according to the local mix of industry types.** The latter could be readily obtained from the ZIP code Business Patterns data (U.S. Census Bureau 2011).

This modeling strategy is illustrated in Figure 8. As shown, if FG and FTG models are estimated for the various industry sectors, they could be mapped into *any* local definition of land use classes using properly defined mixing functions that reflect the proportions in which the different industry sectors—e.g., the number of wholesale trade and eating and drinking places—are found in that particular jurisdiction. Among other things, this modeling strategy enables one to take full advantage of the CFS micro-data, and to match the resulting models to the land use classes currently in use by the relevant transportation agencies.

Recent studies in urban areas such as Seattle, Washington, Sacramento, California, and San Francisco show clear descriptions of the economic benefits of freight activities at the regional level. They also clearly describe the negative impacts of freight activities at the local level, such as conflicts with neighboring community developments, noise, etc. (see Cambridge System-

Copyright National Academy of Sciences. All rights reserved.



Note: In this example, the weighting factors (Ws) correspond to the mix of industry sectors (i.e., number of establishments per industry sector) for a given land use.

Figure 8. Schematic of proposed approach.

atics, Inc. 2010b; The Tioga Group et al. 2006; Hausrath Economics Group and Cambridge Systematics, Inc. 2004). In these regions, there is a growing maturity with respect to understanding freight and land use, which provides an opportunity to utilize local knowledge to advance FG and FTG models.

It is important to understand that explicitly modeling FG and FTG separately is very convenient. Table 25 shows a summary of the key pros and cons associated with the use of the different metrics and approaches. The most obvious feature of the table is that there are many tradeoffs to consider. However, from the conceptual point of view, using tonnage to measure the FG has obvious advantages, such as the following:

- It enables one to treat FG and FTG as separate concepts.
- It enables one to explicitly consider the shipment size and its impacts on vehicle/mode choice.
- It is expected to have a solid connection to the kind of economic variables used in transportation planning forecasts.

This alternative, however, does require a complementary step, involving a simple model to estimate freight traffic from the estimates of tonnage. This could take the form of a lookup table that estimates FTG as a function of the cargo produced/received. These estimates must also take into account the generation of empty trips, which typically represent 20% of truck traffic in urban areas, and 30–40% of interstate truck traffic.

Although these approaches require commodity flow data, this should not be problematic because the data can be obtained from the CFS. The CFS micro-data are available for use at the Regional Data Centers sponsored by the Census Bureau, though securing access requires a lengthy process. Since the CFS micro-data is collected from about 100,000 establishments and

Table 25. Advantages and disadvantages of different freight demand metrics.

Approach / Metric	Advantages	Disadvantages
Freight Generation Models using Commodity tonnage	Solid connection to economic variables	Requires the use another model to estimate vehicle-trips (loaded and empty) generated
	Able to consider the role of shipment size	
	Could use the CFS micro-data	Requires commodity data
Freight Trip Generation Models Using Vehicle-trips	Easy to measure	Weak/No connection to economic variables
	Consider loaded and empty trips	In some cases, not related to business size
Freight Trip Generation Models Using Deliveries	Easy to measure	Weak/No connection to economic variables
		In some cases, not related to business size
		Only reflects the loaded trips

Copyright National Academy of Sciences. All rights reserved.

contains about 4.9 million shipments nationwide, it should provide a solid foundation for FG/FTG modeling. For reference purposes, the authoritative and important ITE *Trip Generation Manual* contains data collected from about 4,800 trip generation studies (Institute of Transportation Engineers, 2008). This means that the CFS micro-data could provide, every 5 years, an amount of data equivalent to 20 ITE *Trip Generation Manuals.* Furthermore, by using the CFS micro-data, the freight modeling community would need to do the following:

- Use the best approach from the conceptual point of view that decouples the generation of demand from the generation of freight traffic.
- Take advantage of a massive data set that is collected every 5 years and covers almost all relevant economic sectors in the nation.
- Produce FG/FTG models for all freight-related industry sectors across different regions.
- Map these industry sector models into the various definitions of land use adopted by the different MPOs and state DOTs using mixing distributions that reflect the local employment distributions.
- Still require to estimate freight traffic from the FG models developed from the CFS micro-data. However, in the opinion of the team, this is a small price to pay for exploiting the potential of the CFS data.
- Develop simple computational tools to convert the FG and FTG models by industry sectors into models that match the land use classes used by the transportation agencies in charge of the analyses as well as estimate freight traffic from the FG models developed from the CFS micro-data.

Summary

The analyses indicate that the ability of land use variables to explain FG and FTG depend on how well the different land use classes are able to represent the economic/logistic processes that impact FG and FTG. In this context, if a land use class encompasses a set of disparate industry sectors with very different FG and FTG patterns, the corresponding land use variables cannot be expected to be good explanatory variables. On the other hand, if the industry sectors under a given land use class exhibit similar FG and FTG patterns, land use variables are likely to do a better job. As a result of these considerations, ensuring a good match between the land use class and the industry sectors within it is a must. Achieving this would require:

- Developing FG and FTG models by industry sector that could be mapped into the land use classes used by a given planning agency, using an appropriate mixing function.
- Fostering the adoption of land use classification systems that provide a good match between the land use classes and the underlying economic sectors.

Copyright National Academy of Sciences. All rights reserved.

CHAPTER 5

Freight Trip Generation Models and Data Collection

This chapter summarizes the current literature on FG and FTG modeling, and associated data collection. The review for FG and FTG provides a comprehensive review of the state-of-the-art research and practice in the area, with critical examination of the technical merits, advantages, and disadvantages of different FTG methods and models. The review for data collection focused on techniques and sources.

Freight Trip Generation (FTG) Modeling

The review encompassed the state-of-the-art practices in the area, both domestic and international. The various factors that should be considered in developing and analyzing freight modeling techniques are given in Table 66 in Appendix D. They include: dependent and independent variables, levels of aggregation and geography, estimation techniques, and model structure. In terms of the dependent variable, from the models contained in the reviewed references, 47% use vehicle trips; 38% use commodity tonnage; and 15% use a combination of vehicle trips (usually for internal-internal trips) and commodity tonnage (for the rest of the flows). About 38% of the models are aggregated, 48% are disaggregated, and others (14%) cannot be determined from the review. The independent variables used include: employment by industry sector (49%); building area (9%); commodity type (13%); land use (2%); and other variables (27%). As for modeling techniques, 25% use least square, 10% use trip rates, 6% use multi-classification analysis, and 33% use IO analysis. These three modeling methods constitute the majority of the FTG models used in practice (or about 74%). In addition, from the model information that is known, most of the models are linear (22 out of 33), while a small fraction of them are nonlinear.

A summary of the various FTG models that were reviewed is given in Table 68 in Appendix D. A breakdown of the features of the models by level of geography showed that the majority of the models are for states (35%) and metropolitan areas (39%). The models are grouped into vehicle-trip-based models and commodity-based models. Appendix D contains a comprehensive review of the literature for both types of models.

Review of TRB Synthesis Reports

FTG has been a focus of several NCHRP studies, including *NCHRP Synthesis 298, NCHRP Synthesis 384, NCHRP Synthesis 358,* and *NCHRP Synthesis 606.* Brief summaries of these studies are provided in this section.

NCHRP Synthesis 298: Truck Trip Generation Data

This synthesis report mainly identifies available data sources and data collection techniques, and assesses the current state-of-the-practice in truck trip generation. The report discusses key considerations in the development of truck trip generation data needs, which include uses of truck trip generation data, trip purposes, estimation techniques, and data collection. Two types of trip generating models are discussed: vehicle-based models and commodity-based models. Twelve vehicle-based travel demand models and 14 commodity-based travel demand models were presented. The report also reviews numerous projects related to FTG, especially on the topics of FTG data needs and survey methods. It lists three major methods to estimating truck trip generation data: estimation of simple rates, linear regression models, and commodity flow models. In chapter three of the report, data sources that were used to estimate truck trip generation in practice are compiled. This report also summarizes seven most commonly used approaches to collecting data for truck trip generation, including trip diaries, classification counts, published commodity flow data, collected commodity flow data, shipper/carrier/special generator surveys, intercept surveys, and published rates.

Copyright National Academy of Sciences. All rights reserved.

NCHRP Synthesis 384: Forecasting Metropolitan Commercial and Freight Travel

This synthesis reviews methods of freight and commercial vehicle forecasting in practice, together with promising methods emerging from ongoing research. The primary focus of the report is on metropolitan-level forecasting, although some consideration is also given to statewide freight forecasting models. The report reviews application of the four-step model process to freight demand modeling, including the process of FTG. Major sources of planning information to freight and commercial vehicle forecasting are presented in this report. Besides the four-step model process, the report also summarizes six emerging methods in freight demand models: time series modeling of freight traffic growth; behaviorally focused demand models; commodity-based forecasts, including interregional IO models; methods that forecast flows over multimodal networks; micro-simulation and agent based simulation (ABS) techniques; and models that incorporate supply chain/logistics chain considerations. The report also lists several methods acquiring FTG results, including developing truck trip generation rates, borrowing trip rates from one or more other regions, introducing special generators, and using external stations. On urban freight data collection, the report presents two major methods: vehicle classification counts and origin-destination surveys, which include roadside intercept surveys, mail and telephone surveys, establishment surveys and carrier surveys.

NCHRP Synthesis 358: Statewide Travel Forecasting Models

This synthesis examines statewide travel forecasting models, including passenger vehicles and freight components. It reviews the types and purposes of models being used. Data requirements, survey methods, funding, and staff resources are also reviewed to investigate the limitations and benefits of the models. In the survey of statewide freight forecasting practice, the report defines two fundamentally different styles of freight forecasting: direct forecast of vehicle flows without reference to commodities; and forecasting of commodities, using the commodity flow forecast to estimate vehicle flows. The report includes five case studies, two of which are on freight components, including the Virginia freight component and the Wisconsin freight component, two are on passenger components, and one is a combined passenger and freight component. The report concludes that most statewide models are similar in structure to four-step urban transportation planning models, and that there exists no well-accepted definition of best practice in statewide models. The report points out several distinct trends in recent statewide model development, such as the emerging of commodity-based models and more effective use of GIS to manage data, among others.

NCHRP Report 606: Forecasting Statewide Freight Toolkit

This report presents an analytical framework for forecasting freight movements at the statewide level to develop forecasting models. The framework includes a tool kit of data collection techniques, analytical procedures, and computer models. It includes management approaches, decision-making procedures, and performance evaluation methods, which help improve statewide transportation under the increment of freight demands. The report also summarizes several classes of data sources, including: model development (local and national surveys, compilations); flow conversion (tons to vehicles and tons to value); network data (modal network and intermodal terminals); forecasting data (population and employment); and validation data and classification schemes (commodity classification and industry classification). Meanwhile it presents five forecasting models and performance measures. Ten case studies of statewide freight modeling projects are reviewed, including FTG models, and model application and validation.

NCHRP Project 08-36/Task 79: Scoping Study for a Freight Data Exchange Network

This report investigates the feasibility of building a freight data exchange network to provide access to higher quality freight data. It considers a centralized data repository from which data providers and users can access freight datasets, metadata, or reports of data quality. In this network, data providers can upload data while end-users can download them in the form of summary tables, reports, and customized tabular data. The report describes various types of freight-related datasets and suggests potential ways to utilize them, including the CFS, Rail Waybill Data, foreign trade data, Freight Analysis Framework 2 (FAF2), TranSearch Commodity Flows Database, freight databases from local and regional studies, socio-economic data from regional studies, and other data sources. It also conducted interviews with potential data users and providers.

NCHRP Synthesis 410: Freight Transportation Surveys

This synthesis examines the sample size, data accuracy, data comprehensiveness, and survey objectives for freight transportation. It also includes a discussion of the feasibility and benefits of linking survey data with data from roadway and sensors.

Copyright National Academy of Sciences. All rights reserved.

NCHRP Report 404: Innovative Practices for Multimodal Transportation Planning for Freight and Passengers

This report reviews innovative agency practices and methods in multimodal planning. For a set of case studies, the report monitors the performances and public involvement in planning effects on rural areas. It also mentions fiscal constraints in planning and programming.

Summary

The following summarizes the findings derived from the literature review of FG and FTG models:

- **The bulk of the studies have focused on FTG, not FG.** As illustrated in the literature review, the bulk of the models are based on vehicle trips, though a handful of studies consider FG in the context of IO models. This stands in contrast with European practices that emphasize commodity-based approaches that incorporate FG modeling as an endogenously determined variable.
- **It is not yet clear which modeling techniques are the best.** Although extensive research has been conducted in the last several decades on developing FG/FTG models, there is no study to compare specifically the performances of these techniques; there is no consensus yet regarding which models can produce the most accurate results. This is reflected by the fact that different agencies are applying a variety of different freight (trip) generation models (see Appendix E) due to the lack of a commonly agreed "best practice" model. However, based on previous research experiences, the research team does believe that certain modeling techniques, such as disaggregated models and regression analysis, do have advantages that stand out among all modeling techniques.
- **There are no consistent definitions of trucks, truck trips, and land use classes.** This point is made by the ITE *Trip Generation Handbook* and other publications. The inconsistent definitions of these important variables contributes to shaky results regarding which factors are the most important in explaining FG/FTG, and which modeling techniques are the most effective. There is thus a need to standardize those definitions so that more consistent FG/FTG modeling approaches could be developed.

FG and FTG Modeling Practice, Evaluation Criteria, and Evaluation Process

Current practices, evaluation criteria and processes, both domestic and international, of FG and FTG modeling were reviewed. The different modeling applications of FG and FTG modeling are classified (Fischer and Han 2001) into two categories: planning applications and engineering applications. The objective of planning applications is to provide estimates of FG/FTG for conglomerate users for the purpose of transportation planning at the state, regional, corridor, and urban level. Typically, these are medium- and long-term studies aimed at answering questions about medium- and long-term capacity needs and economic development. Engineering applications are intended to provide key input to a variety of engineering design questions concerning facility design issues, traffic operation studies, site impact analyses, provision of on/off-street parking for trucks, etc. In some cases, the analysis could focus on a single establishment, a single location with multiple establishments, or an entire area such as a downtown area. These studies emphasize short-term analyses and improvements. A review of both types of applications is provided in Appendix E.

Refer to Appendix D and Appendix E for a comprehensive description of the current literature and practice in FG and FTG modeling.

Data

The literature review focused on data collection techniques and sources. The major finding was that there is a lack of primary FG/FTG data. This is a major issue because of the need to effectively incorporate freight transportation into the planning process. The fact that many of the sources of FTG models are now dated, and that one of the most important primary freight data sources, the CFS, has not been widely used for freight modeling exacerbates this problem. Appendix F discusses in detail the literature review and findings for data collection, data needs, and sources. During the review, a number of the analyzed publications were found to contain FG and FTG models. However, these publications are mostly in the form of articles, research/synthesis reports, and books. This static format is not conducive to quick consultation and interactive queries. It was important, therefore, to use database tools to compile the information to make it more readily available. In this way, the data could be:

- Stored and made available on the Internet, which enables practitioners and researchers to have access to it when needed.
- Integrated with an expert system that, in return to a query about trip rates, would provide the closest match.

As part of NCFRP Project 25, the research team compiled a comprehensive FG and FTG model database. The database can be accessed at: http://transp.rpi.edu/~NCFRP25/FTG-Database.rar. The information in the NCFRP Project 25 database encompasses thousands of lines of data assembled over

Copyright National Academy of Sciences. All rights reserved.

Table 26. Summary of models contained in the database.

Type of Model	
Production	689
Attraction	720
Not Specified	481
Total	1890

Type of Independent Variable	
Employment	565
Area	786
Establishment	278
Household	47
Individuals	15
Fleet	36
Industry segment	2
Income	1
Land use	211
Parking	1
Traffic volumes	2
Sales	5
Cargo	13
Other	41

several years. The database is organized into three primary parts: publications, models, and case studies. The publications section contains an expansive literature database on FG/FTG references (e.g., books, journal papers, research reports, synthesis reports) including bibliographic citations. The reference table contains 46 records of which 15 contain case studies. The case study section of the database summarizes the case studies contained in the publications set. It details information such as project title (or chapter title when referenced in the particular project report) and location. Within the 15 publications that contained case studies, there are 233 individual case studies, most of which are reports from NCFRP or NCHRP. The model database summarizes the FG/FTG models in the literature. Models include, but are not limited to, trip rates, regression, and time series. Fields for this table include level of aggregation, geography, estimation technique, model structure, time unit, and independent variables from the literature. Table 26 summarizes the type of models contained in the database and principal independent variables.

A user manual for the database is found in Appendix G. This document presents detailed information about the variables identified and briefly explains the basics of opening the database; how to navigate through the different sections (e.g., models, publications and case studies); and provides a usability walkthrough with examples such as searching for and viewing: the different models (trip rates and regression analysis) with employment and food; production models based on employment; and publications containing models dependent on employment.

Surveys

From the review, it was found that carefully designing an FTG survey was necessary to collect data to conduct FTG modeling. For this purpose, a sample of FTG surveys was reviewed. These included: the mail survey in Bartlett and Newton (1982); the receivers and carriers surveys in Holguín-Veras (2006); and the mail survey for truck trip generation at container terminals (Holguín-Veras et al. 2002).

Bartlett and Newton (1982) developed a specific questionnaire to request information from a select set of firms in three areas of England. The main intent was to derive "goods vehicle" trip generation and attraction at a wide range of industrial and commercial firms. The survey collected data on: (a) type of business activities; (b) total number of employees; (c) number of office employees; (d) site area; (e) gross floor area; (f) numbers of goods vehicles operated from the address (car-based vans upwards); (g) average numbers of journeys made per week by these vehicles, split into a number of vehicle weight categorizes; (h) average number of calls made per week by all visiting goods vehicles (including any calls by vehicles owned by the firm but based elsewhere); (i) details of any other mode of transport in use by the firm; and (j) location of the firm on a map attached to the questionnaire. A mail-back questionnaire was developed based on these questions and mailed to selected firms. The firms were sampled and analyzed later on based on their SIC codes. The SICs were further grouped into five categories: (1) manufacture; (2) service; (3) construction; (4) wholesale/dealer; and (5) haulage/distribution. The survey resulted in a high response rate (more than 60%), as indicated in Bartlett and Newton (1982).

To study the effect of off-hour delivery (OHD) in the New York City region, both receivers and carriers surveys were designed (Holguín-Veras 2006) to collect FTG related data. The surveys were conducted for Manhattan and Brooklyn. In these surveys four groups of questions were designed for both receivers and carriers: (1) whether the company is making deliveries in Manhattan; (2) the company's current operations and flexibility in terms of making deliveries; (3) scenario testing regarding OHD; and (4) characteristics of the company, including business type, types of commodities, the number of truck drivers, among others. The survey was con-

Copyright National Academy of Sciences. All rights reserved.

ducted using computer-aided interviews, and the response rate was about 30%.

A mail-back survey was designed by Holguín-Veras et al. (2002) to collect information regarding truck trip generation at container terminals. Two sets of questions were designed. The first set focused on general information about the container terminal including the terminal name, how many TEUs are handled per year by the terminal, operational hours of the gates, number of lanes at the gates, number of berths, number of gantry cranes, percentages of containers carried by railroads, trucks, and barges, the slowest and busiest months, and the number of ships visiting the terminal each day for a typical week. The second set was designed for truck traffic information only for a typical day. The following specific questions were asked for both the inbound and outbound cargos: the numbers of trucks with loaded and empty containers, respectively; daily truck traffic in the terminal; the morning and afternoon traffic peak hours; and the numbers of trucks going through gates during the morning and afternoon peak hours, respectively.

Building on these documented experiences and taking into account the Freight Data Architecture (Journal of Commerce 2011), so that the data collected is amenable for data pooling, a survey prototype was developed as part of the NCFRP Project 25 research for use in FTG studies. The survey prototype, which also inquires about service trips, can be found in Appendix H. This survey prototype:

- Was designed for consistency with the Freight Data Architecture being developed as part of NCFRP Project 12, "Specifications for Freight Transportation Data Architecture" (Journal of Commerce 2011), so that the data collected is amenable for data pooling; a survey prototype is suggested for use in FTG studies.
- Enables practitioners and researchers to have access to a basic survey design that they could tailor to their specific needs.
- Facilitates data pooling (as a result of using the Freight Data Architecture), thus enabling practitioners and researchers to add data to a centralized database.
- Can be used to feed data and models to the relational FG/FTG database.

The survey instrument was pilot tested and the collected data was used to validate the models estimated with the case studies.

Copyright National Academy of Sciences. All rights reserved.

CHAPTER 6

Case Studies

A review of the literature and current practices in freight modeling (see Appendices D and E) revealed several information gaps. As discussed in Chapter 3, these gaps relate mainly to emerging land uses where there is a lack of modeling approaches that can effectively reproduce the characteristics of FTG. The objective of this chapter is to fill those information gaps by assessing the efficacy of different analysis techniques and land use classifications through a set of case studies. In addition, the procedure presented in this report can become the benchmark for future FTG studies. The case studies include the following:

- An establishment-based dataset with 76 furniture stores in Midwestern States, already with basic land use information and company characteristics (the company asked that its name not be divulged).
- An establishment dataset with about 400 completed questionnaires of receivers of cargo in Manhattan and Brooklyn containing information about deliveries and company characteristics.
- An establishment dataset with about 400 completed questionnaires of private and common carriers of cargo in Northern New Jersey and New York containing freight trip information and company characteristics.
- Comparison of deliveries for a number of grocery stores in Manhattan (NY) and eight supermarkets in the Puget Sound region.

These datasets include economic information about the businesses and facilities, their locations, size, revenues, industries and lines of business, and trip data (e.g., number of truck trips per day/week, shipment sizes, frequencies, empty trucks, type of trucks, hours of operations, and in some cases, truck origins and destinations). In addition, the datasets are complemented with land use information.

Description of the Datasets

This section includes a description of the various datasets.

Midwestern States Furniture Chain Dataset

The data for furniture Chain A (the company's real name not divulged) contain the information of 76 stores in 18 states in the Midwestern and Eastern parts of the United States. Figure 9 shows the number of stores by State: Illinois has 17 stores; followed by Ohio (16 stores); Michigan (8 stores); and Indiana (7 stores). The team studied and analyzed data for Illinois, Ohio, Michigan, and Indiana as four individual case studies; the North East-Mid Atlantic states (Connecticut, Delaware, Maryland, Massachusetts, New York, Pennsylvania, Virginia, and West Virginia) and the rest of the Midwest states (Iowa, Kentucky, Minnesota, Missouri, Wisconsin, and Nebraska) were studied as separate case studies. This produces a total of six individual case studies. Each dataset includes the number of deliveries to the stores; the number of pallets per delivery; store addresses; store location characteristics (i.e., off-mall-base and mall-base stores); and store types (i.e., combo, conventional, and outlet stores). Combo type refers to stores that sell both conventional and children's furniture. On the other hand, outlet type refers to stores that handle returned and outdated furniture. As additional information, the distribution center manager revealed that the company is shifting the stores from the malls to off-mall locations. These new stores are mostly the combo type.

Stores receive one or two weekly deliveries throughout the year. For this chain, the most important information for tracking the performance of stores is the number of pallets delivered per week. A pallet is the basic unit of measure used for recording and planning the volume of shipments, the approximate dollar value of each shipment, and the number of trucks required for a delivery. According to the interviewee, the average dollar value of furniture per pallet is $515. Up to 28 pallets can be shipped in a 53-foot container. Most trucks leave the distribution center when they are almost full. Thus, it is possible to approximate the number of truck trips originating from the distribution center by dividing the total number of pallets by 28. However, with this data, it is not

Copyright National Academy of Sciences. All rights reserved.

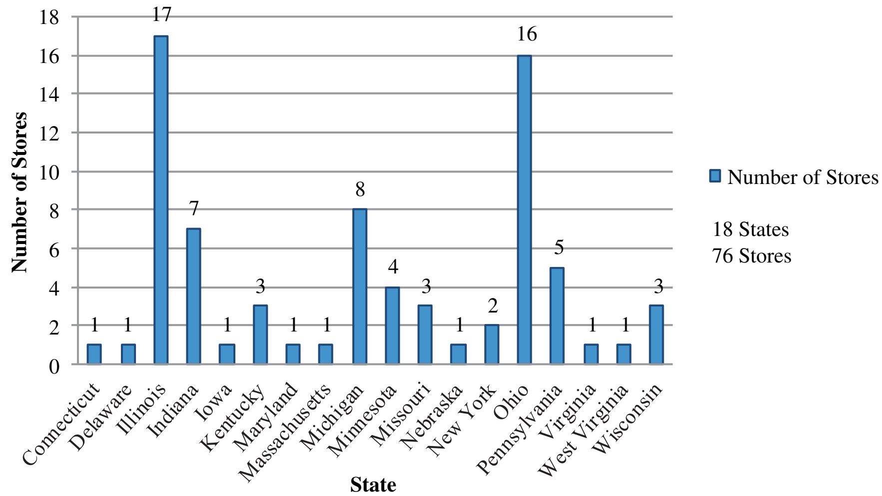


Figure 9. Number of stores by states.

possible to approximate the number of truck trips to each store, since one routing covers 2 to 3 stores. For example, the maximum number of pallets that a store receives is 18, which is below the maximum capacity of a 53-foot container. Instead, the weekly pallet information can be used to estimate its relationship with the store-related characteristics.

Since the information on the number of employees, sales volume, and size of individual stores was difficult to obtain from the survey, it was purchased from InfoUSA. However, the correlation plot reveals that employees and sales volume are highly, though not perfectly, correlated. Because it is not certain whether the correlation is real (the most plausible case is that the company allocates the number of employees at each store based on sales) or artificial (e.g., InfoUSA® estimates one of them based on the other), caution is essential when using this data. To avoid multicollinearity, only one of the variables is used to estimate the regression models. As sales is not a useful variable for planning purposes, the number of employees was chosen as the independent variable for the regression models. However, employment data was available for 58 of the 76 stores of the dataset. The regression models considered only the observations that have available employment data. Figure 9 shows the number of stores by state.

New York City (NYC) Carriers and Receivers Dataset

As part of a project conducted for the New York State Department of Transportation (NYSDOT), disaggregated data was collected at the establishment level through two surveys targeting carriers and receivers. The questionnaire inquired about company attributes and operational and FTG patterns, in addition to how participants would react to different scenarios concerning off-hour deliveries. To develop the data collection plan, records were purchased from the Dun and Bradstreet (D&B) database for Manhattan and Brooklyn. Taking into consideration the area of study, and shipping and receiving patterns, companies were randomly selected from the purchased sample. Companies were selected for each of the SIC in the D&B database. In the random selection, more weight was placed on businesses prone to the transport of commodities (focus of this study) and less on the ones on service related industries.

The receiver sample was selected from the list of receivers in Manhattan with more than five employees. For the Manhattan carriers' case, companies were selected from two groups: for-hire carriers (those that provide services to the open market); and private carriers (those that provide transportation service to a parent/related company). The selected carriers had at least 25 employees and were based in some counties of New York and New Jersey.

For the Brooklyn case, the sample plan considered Brooklyn receivers/intermediaries and carriers from Brooklyn and New Jersey. Pure receivers only receive goods, while intermediaries both ship and receive goods. A filter was used considering companies with more than five employees. After designing the data collection plan, the surveys were sent to the Eagleton Institute of Rutgers University to obtain the data, using computer-aided telephone interviews (CATI). A complete description of the data collection plan is found in the Project: Potential for Off-Peak Freight Deliveries to Commercial Areas website[1] and final report[2].

The data collection process resulted in a sample for the Manhattan and Brooklyn receivers comprised of 362 complete observations. Table 27 shows the breakdown of their

[1]http://www.rpi.edu/~holguj2/OPD/index.html

[2]Holguín-Veras, J. (2006). Potential for Off-Peak Freight Deliveries to Congested Urban Areas Rensselaer Polytechnic Institute. http://www.rpi.edu/~holguj2/OPD/OPD_FINAL_REPORT_12-18-06.pdf

Copyright National Academy of Sciences. All rights reserved.

Table 27. Breakdown of receivers by SIC, NYC.

SIC	SIC description	Number of establish-ments	% of establish-ments
58, 54, 20	Eating and Drinking Places, Food Stores, Food and Kindred Products	88	24.31%
51	Wholesale Trade: Nondurable Goods	58	16.02%
50	Wholesale Trade: Durable Goods	58	16.02%
59	Miscellaneous Retail	46	12.71%
17	Construction-Special Trade Contractors	18	4.97%
56	Apparel and Accessory Stores	15	4.14%
57	Home Furniture, Furnishings, and Equipment Stores	13	3.59%
52	Building Materials, Hardware, Garden Supply, and Mobile Home Dealers	10	2.76%
23	Apparel and Other Finished Products Made From Fabrics and Similar Material	8	2.21%
15	Building Construction-General Contractors And Operative Builders	7	1.93%
34	Fabricated Metal Products, Except Machinery and Transportation	5	1.38%
25	Furniture and Fixtures	6	1.66%
39	Miscellaneous Manufacturing Industries	5	1.38%
22	Textile Mill Products	4	1.10%
24	Lumber and Wood Products, Except Furniture	5	1.38%
27	Printing, Publishing, and Allied Industries	2	0.55%
26	Paper and Allied Products	2	0.55%
55	Automotive Dealers and Gasoline Service Stations	2	0.55%
94	Administration of Human Resource Programs	2	0.55%
32	Stone, Clay, Glass, and Concrete Products	1	0.28%
16	Heavy Construction Other Than Building Construction-Contractors	1	0.28%
30	Rubber and Miscellaneous Plastics Products	1	0.28%
35	Industrial and Commercial Machinery and Computer Equipment	1	0.28%
36	Electronic and Other Electrical Equipment and Components, Except Computer	1	0.28%
38	Measuring, Analyzing And Controlling Instruments; Photographic, Medical	1	0.28%
74	Business Services	1	0.28%
96	Administration of Economic Programs	1	0.28%
Grand Total		**362**	**100.00%**

primary industry types. As highlighted, about a quarter of the companies are in the food related sector, and another third are in the wholesale durable and non-durable goods trade. Other sectors include: retail, construction, apparel and accessory stores, and furniture and building materials. Additional information available in the receivers sample consists of: number of deliveries received, type of facility, employment and commodities received, among others. The dataset was complemented with Dun and Bradstreet information.

In terms of business size, most of the establishments in the sample were small- to medium-sized, with about 5 to 50 employees (80%) (see Table 87 in Appendix I). This is consistent with the overall breakdown for establishments located in Manhattan and Brooklyn, where more than 90% are in this same range of employment (U.S. Census Bureau 2010b).

The data collection process resulted in a sample for New York and New Jersey carriers that consisted of 339 complete observations. Table 1 shows the breakdown of the sample by industry sector.

As shown in Table 28, close to 45% of the sample was represented by motor freight transportation and warehousing, and approximately another 40% was represented by wholesale trade, both durable and non-durable goods. Rounding out the top six sectors were food related establishments (4%); other transportations services (3%); and the construction sector (3%). All other sectors represented in the sample each accounted for 1% or less. As with the receivers sample, data on number of trips, type of facility, employment and commodities transported, among other data were collected for the carriers sample. In terms of business size measured by number of employees, most of the sample is small- to medium-sized. Establishments with less than 50 employees account for almost 75% of the carriers' sample (see Table 88 in Appendix I).

The NAICS, adopted in 1997 to replace the SIC system, is the standard used by Federal statistical agencies in classifying businesses. Accordingly, the sample was reclassified by the NAICS. The NAICS is a more disaggregated system than

Copyright National Academy of Sciences. All rights reserved.

Table 28. Breakdown of carriers by SIC, NYC.

SIC	SIC description	Number of establish-ments	% of establish-ments
42	Motor Freight Transportation and Warehousing	150	44.25%
51	Wholesale Trade: Nondurable Goods	65	19.17%
50	Wholesale Trade: Durable Goods	65	19.17%
58, 20	Eating and Drinking Places, Food Stores, Food and Kindred Products	12	3.54%
47	Transportation Services	9	2.65%
17	Construction-Special Trade Contractors	8	2.36%
59	Miscellaneous Retail	3	0.88%
30	Rubber and Miscellaneous Plastics Products	3	0.88%
34	Fabricated Metal Products, Except Machinery and Transportation	3	0.88%
26	Paper and Allied Products	3	0.88%
73	Business Services	3	0.88%
56	Apparel and Accessory Stores	2	0.59%
52	Building Materials, Hardware, Garden Supply, and Mobile Home Dealers	2	0.59%
23	Apparel and Other Finished Products Made From Fabrics and Similar	2	0.59%
57	Home Furniture, Furnishings, and Equipment Stores	1	0.29%
15	Building Construction-General Contractors And Operative Builders	1	0.29%
25	Furniture and Fixtures	1	0.29%
39	Miscellaneous Manufacturing Industries	1	0.29%
24	Lumber and Wood Products, Except Furniture	1	0.29%
55	Automotive Dealers and Gasoline Service Stations	1	0.29%
33	Primary Metal Industry	1	0.29%
35	Industrial and Commercial Machinery and Computer Equipment	1	0.29%
36	Electronic and Other Electrical Equipment and Components, Except Computer	1	0.29%
Grand Total		**339**	**100.00%**

SIC, but when comparing both systems at the 2-digit level, NAICS is more aggregated. Furthermore, a comparison of the aggregated industries (see Table 89 in Appendix I), reveals that some 2-digit aggregated SIC industries correspond to more than one 2-digit NAICS. In the receivers' sample, for instance, some establishments in the food stores (SIC 54) industry match to manufacturing (NAICS 31) industry, and others to retail trade (NAICS 44). This has major implications for modeling and planning efforts, as resulting FTG patterns for an industry identified using one industry classification system cannot be generalized for the other.

In addition, the dataset was geo-coded using addresses of the establishments to include the land use information. The geo-coded firm location was spatially joined to zoning polygons (the reference file can be found in NYC Department of City Planning website[3]) that contain the land use codes designation used by NYC. The team obtained the Tax-Lot Polygon Feature Class of the Department of Finance's Digital Tax Map that was merged with the PLUTO™ attribute data for 2006, defined as the attribute table of property information associated with each tax lot[4]. The spatially joined data was exported into Excel for analysis; this file was then converted to comma separated values (csv) format and exported to econometric software, where the complete dataset was used for FTG research.

After studying the dataset, it was found that the establishments are located in 81 different land use categories, as defined in the City of New York Zoning Resolution (NYCZR). These classes were reorganized into the groups shown in Table 29. These groups are related to commercial, manufacture, and residential land uses.

Table 29 shows the distribution of establishments by land use; more than a quarter of the establishments are in the M-1 Light Manufacturing district that typically includes wholesale trade. A quarter of the establishments are located in districts zoned Residential. These establishments provide retail and other services to neighborhoods, thus playing an important role for estimating FTG. (A detailed description of land uses can

[3]http://www.nyc.gov/html/dcp/html/bytes/dwnzdata.shtml

[4]The Tax Parcel Attributes Table also contained zoning designations. This designation was compared with the zoning polygons and found sixteen inconsistencies; upon further investigation it was found that they do not influence the outcome of the models.

Copyright National Academy of Sciences. All rights reserved.

Table 29. Breakdown of receivers by land use according to NYCZR, New York City.

Land Use	Land Use Description	Number of establish-ments	% of establish-ments
Light manufacturing district (M1)	Manufacturing district: light industries include woodworking service, auto storage and repair shops, and wholesale service and storage facilities	102	28.18%
Residential district (R)	Residential district: all residence districts permit most community facilities, such as schools, houses of worship and medical facilities. Certain facilities are not permitted or are restricted in size	100	27.62%
Central business district (C5)	Central business districts: offices, high-end retail establishments and continuous retail frontage	44	12.15%
Central business district (C6)	Central business districts: corporate headquarters, large hotels, entertainment facilities, retail stores and high-rise residences	40	11.05%
Heavy manufacturing district (M3)	Manufacturing district: heavy industries that generate traffic or pollutants. Typically include power plants, solid waste transfer facilities and recycling plants, as well as fuel supply depots	32	8.84%
Retail district (C1)	Small retail and service shops: grocery stores, restaurants and beauty parlors	18	4.97%
General goods district (C4)	Large stores with general goods: specialty and department stores, theaters and other commercial and office uses	13	3.59%
General services district (C8)	Heavy repair shops and automotive: automobile showrooms and repair shops, warehouses, gas stations and car washes (all commercial uses are permitted in C8 Districts)	5	1.38%
Retail and services district (C8)	Small retail and service shops: same as C1 but permits funeral homes and repair services	4	1.10%
Middle manufacturing district (M2)	Manufacturing district: middle ground between light and heavy industrial districts, more noise and vibration than in M1 are allowed, smoke is permitted and industrial activities need not be entirely enclosed	4	1.10%
Grand Total		**362**	**100.00%**

be found in the supplemental materials and appendices of the Task 11: Case Studies Report, available online[5].)

As shown in Table 29, more than two thirds of establishments in the sample are located in commercial and manufacturing districts. Furthermore, two thirds of establishments in commercial zones are in the Central business district; and about two thirds of establishments in the manufacturing zones are in light manufacturing districts. Overall, results show that the dataset covers the spectrum of land use categories defined in the NYCZR.

After completing the dataset with the required information, the team initiated the process of estimating FTG models. The process is discussed in the following section of this chapter.

A similar analysis was made for the database using the LBCS developed by the APA (American Planning Association, 1994). LBCS provides a consistent model for classifying land uses based on their characteristics. In this system, land uses are classified by refining traditional categories into multiple dimensions, such as activities, functions, building types, site development character, and ownership constraints. (A further description of the dimensions and the classification can be found in the supplemental materials and appendices of the Task 11: Case Studies Report, available online[6]). Table 30 shows the breakdown of the receivers among the LBCS categories.

As shown in Table 30, slightly more than 20% of the establishments are related to retail activities. Wholesale trade of durable goods accounts for 17%, while non-durable goods represent 15% of the total. In addition, food service has a significant share, approximately 16%. In terms of LBCS activity, goods-oriented shopping takes place in 75% of the establishments, while a minor percentage uses land for plant, service, and restaurant activities. There is a significant degree

[5]Available online at http://transp.rpi.edu/~NCFRP25/downloads.shtml

[6]Available online at http://transp.rpi.edu/~NCFRP25/downloads.shtml

Copyright National Academy of Sciences. All rights reserved.

Table 30. Breakdown of receivers by LBCS function and activity, NYC.

LBCS Function	Land Use Description	Number of establish-ments	% of establish-ments
Retail	Retail sales or service: automobile sale, heavy consumer goods sale, durable consumer goods sale (exclude grocery stores), consumer goods, retail food and beverage not included in the "Grocery LBCS function"	76	20.99%
Durable goods	Wholesale trade establishment: durable goods	62	17.13%
Food service	Food services: those that prepare meals, snacks and beverages for immediate consumption as primary economic function	57	15.75%
Nondurable goods	Wholesale trade establishment: nondurable goods	54	14.92%
Miscellaneous 2	Include other economic use of the land such as communication and information, education and other institutions, construction related business	33	9.12%
Miscellaneous 1	Manufacturing: include wood, paper, and printing products, chemicals and metals manufacturing, and miscellaneous manufacturing	26	7.18%
Grocery	Retail sales or service: include grocery stores, supermarkets, bakery, specialty food stores, fruit and vegetables stores, beer, wine and liquor store	25	6.91%
Pharmacy	Retail sales or service: include pharmacies, drug stores, cosmetic and beauty supplies, scientific and technical services	16	4.42%
Textiles	Manufacturing: include establishments that transform natural or synthetic fiber into products or manufacture textile products by knitting, cutting, and sewing fabric.	13	3.59%
Grand Total		**362**	**100.00%**

a) By LBCS function

LBCS Activity	Land Use Description	Number of establish-ments	% of establish-ments
Goods	Shopping: Goods oriented shopping	271	74.86%
Plant	Plant, factory, or heavy goods storage or handling activities	39	10.77%
Service	Shopping: Service oriented shopping	35	9.67%
Restaurant	Restaurant type activity	16	4.42%
Other	Office activities	1	0.28%
Grand Total		**362**	**100.00%**

b) By LBCS activity

of correlation between function and activity, which prevents considering both as independent variables in econometric models of FTG.

NYC Whole Foods Market Dataset

Whole Foods Market is a chain of grocery stores offering natural and organic foods with more than 270 stores in North America and the United Kingdom. The company has 54,000 team members, 9 distribution centers, 9 regional bake-houses, and more than 8 billion in sales during 2009. The team has the delivery information for five of their stores located in Manhattan, NY. Table 31 shows store names and

Table 31. Whole foods market Manhattan stores.

Store name	Location (NYC)
W. F. Union Square (USQ)	4 Union Square South
W. F. Columbus Circle (CIR)	10 Columbus Circle
W. F. Bowery (HOU)	95 East Houston St
W. F. Tribeca (TRB)	270 Greenwich Street
W. F. Chelsea (CHE)	250 7th Ave

Copyright National Academy of Sciences. All rights reserved.

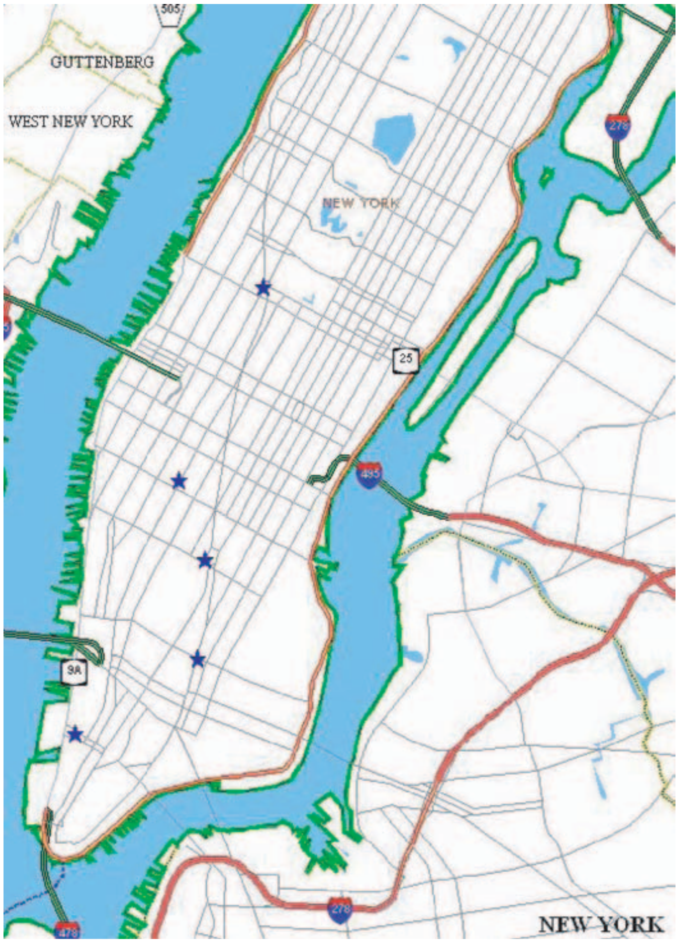


Figure 10. Whole foods market Manhattan stores locations.

locations. Figure 10 shows the location within the Manhattan street network.

The information available includes the weekly delivery schedule and delivery times. Table 32 shows the number of deliveries per store per day, weekday deliveries per employee, weekly deliveries per employee, and the number of vendors serving each store. As shown in Table 32, the store at Columbus Circle (CIR) has the highest number of deliveries per week, while Bowery (HOU) receives about half of the deliveries received by Columbus Circle. From Monday to Friday, the average number of daily deliveries per store ranges between 20 and 39; these numbers drop significantly to between 7 and 11 deliveries per day during Saturday and Sunday. Data indicate that Tuesday is the busiest day of the week for most of the stores. The number of vendors ranges from 46 to 87; Columbus Circle (CIR) is the store served with the largest number of vendors. A detailed hourly breakdown for the number of daily deliveries is presented in Table 90 in Appendix I.

Seattle Region Grocery Stores Dataset

The data for the grocery stores in the Seattle Region includes information from eight stores. These are spread across the Puget Sound metropolitan area (see Figure 11). The stores are all adjacent to major arterials, and have similar square footage, from 23,000 to 53,500 square feet. All are part of national grocery chains except for the Puget Sound Consumer Cooperative (PCC), which is a regional grocery chain. It is part of a nine-store chain owned by approximately 45,000 members living within the Puget Sound region, and the largest consumer-owned natural food retail cooperative in the United States. Five of the surveyed stores are Quality Food Centers (QFCs), which is one store banner of the Kroger Corporation. This is one of the nation's largest grocery retailers, operating 2,468 stores in 31 states under nearly two dozen banners. Two stores are Safeway, another national chain that operates under eight store banners. One store is an Albertsons, which is also part of a national chain that recently became part of the SUPERVALUE family as one of 18 store banners.

All of the stores except PCC have company trucks and operate through regional distribution centers. It is important

Table 32. FTG information for whole foods market stores.

Store name	Emp.	Deliveries							Sub-Total	Week del/emp	Weekday del/emp	Week del/day	Vendors
		M	T	W	R	F	Sa	Su					
W. F. Union Square (USQ)	173	26	28	27	26	30	15	7	159	0.92	0.16	22	46
W. F. Columbus (CIR)	193	35	48	40	34	36	9	9	211	1.09	0.20	30	87
W. F. Bowery (HOU)	167	25	25	23	13	13	13	3	115	0.69	0.12	16	58
W. F. Tribeca (TRB)	173	28	32	31	26	37	14	1	169	0.98	0.18	24	52
W. F. Chelsea (CHE)	140	32	27	36	33	30	11	4	173	1.24	0.23	24	68
Total	846	146	160	157	132	146	62	24	827	0.98	0.18	116	311

Copyright National Academy of Sciences. All rights reserved.

Figure 11. Grocery stores locations in the Seattle region.

to note that the data have been made available to the team courtesy of the research team at the Puget Sound Region Council (PSRC), which conducted the work reported in Ta et al. (2010) and McCormack and Bassok (2011).

Information data was gathered by interviewing individual grocery store managers. In addition, manual on-site truck counts were conducted. Data from manual counts tested the accuracy of the estimates of daily truck deliveries provided by grocery store telephone interviews. Information includes: truck trips, average number of truck deliveries per day, empty trucks, type of trucks, location of facilities, store characteristics, typical hours of deliveries, among others. Information relevant for the present report is summarized in Table 33.

Methodology

This section describes the modeling approach used to characterize the relationship between FTG and land use. FTG refers to the number of vehicle trips required to transport a demanded quantity of goods. It is closely related to FG. However, while FG is associated with the amount of goods demanded by establishments, FTG is determined by the number of vehicles needed to transport them (Holguín-Veras et al. 2011). For the analysis, FTG is quantified using the number of deliveries per establishment. This approach enables the estimation of FTG as a function of land use or industrial sector and employment. Knowing establishment characteristics, FTG can be readily estimated.

To estimate trip generation models, three different approaches were used: standard trip generation rates; linear regression; and Multiple Classification Analysis (MCA). (For a description of MCA, see Ortúzar and Willumsen 2001). The analyses were performed using the industry classification systems SIC and NAICS, land use classification systems, and the NYCZR and LBCS at the disaggregate establishment level.

For the case of linear regression models, the analyses used total employees per establishment as the independent variable,

Table 33. Seattle region grocery stores information.

Store and Location	Square Footage	Emp.	Delivery Hours	Delivery Days	Deliveries Per Day			
					Interviews	Manual Count 1	Manual Count 2	Average* (del/day)
QFC Wallingford	23,000	80	7 am-12 pm	Mon to Sat	10	25	22	19
QFC Kirkland	28,000	70	5 am-11 am	Mon to Sat	9	15	19	14
QFC Mukilteo	37,000	70	5 am-11 am	Mon to Sat	10	18	17	15
QFC Capitol Hill	46,984	100	5 am-11 am	Mon to Sat	9	14	18	14
QFC Lynnwood	53,500	72	5 am-10 pm	Mon to Sat	n/a	13	n/a	13
Safeway Othello	26,092	n/a	n/a	Mon to Sat	n/a	15	15	15
Albertsons Kent	46,000	60	5:30 am-10:30 am	Mon to Sat	15	11	15	14
PCC Issaquah	23,000	95	6 am-2 pm	All days	13	23	30	22

*Note: *The average of the 3 columns is used as the observed number of deliveries (per day) for model comparison.*

Copyright National Academy of Sciences. All rights reserved.

after considering the data collection and forecasting implications of different explanatory factors.

Efforts were made to collect data describing the area of the studied establishments using tax parcels, but the results showed that this method produced questionable estimates. The area variable was therefore discarded from the disaggregated analyses.

The resulting linear regression models, for freight attraction for each land use, fall in one of the following classes:

- **Type S:** Constant FTG per establishment; only the intercept was statistically significant and conceptually valid. FTG does not depend on business size.
- **Type E:** Trip rate per employee; only the coefficient of employment was statistically significant and conceptually valid.
- **Type C:** Linear model with intercept and rate per employee; both the intercept and the coefficient of employment were significant and conceptually valid.

The Root Mean Square Error (RMSE) was the measure used to assess which type of model is more suitable to estimate freight trip attractions and productions. This metric provides a good indication of the absolute fit of the model to the data. Consequently, a lower value of the RMSE means a better fit to the data studied (Greene 1993). In the NYC carriers and receivers study cases, when the regression analyses found that FTG depends on business size, MCA models were applied to estimate the trip rates for each stratum of employment and for each category of land use. (It does not make sense to use MCA stratified by employment level if this variable is not statistically related to FTG.) The research explored different employee groupings to select the number and width of each interval class. The resulting models were grouped according to the type of disaggregated model (S, E or C, as previously described). MCA models were then estimated, where appropriate, for the different groupings and combinations of employee intervals.

Case Study Illustrations

This section includes illustrative applications of the FTG modeling approach.

Midwestern States Furniture Chain: A Comparison of Different Location Structures (In-Mall and Off-Mall)

The dataset used to estimate trip and FG models contains complete information on employment, store location, store type, and state for each observation. There were 58 establishments with complete information.

Following the methodology described previously, two different approaches were applied: standard trip generation rates (per establishment and per employee); and Ordinary Least Squares (OLS). Using the available information, the analyses were performed by disaggregating data at the establishment level. These included average deliveries per establishment, average deliveries per employee, and linear regression models. For the case of regression models per state, the analyses used total employees per establishment and the interaction between employment and store location as the independent variables. On the other hand, for the regression models per store location, the analyses used total employees per establishment and the interaction between employment and store type as the independent variables. This resulted from considering possible data collection and forecasting implications of different explanatory factors.

The resulting linear regression models for freight attraction for each industry/land use took different forms. As done for NYC case studies, three different types of models are considered: type S with constant FTG/FG per establishment; type E with a trip rate per employee; and type C representing a linear model with intercept and rate per employee (see Section 4).

Data for Illinois, Ohio, Michigan, and Indiana were considered as individual case studies to provide a broad range of information. The states with less than seven stores were analyzed in two groups according to their geographic location, and each group was considered an individual case study. The first group was North East-Mid Atlantic (NEMA) states: Connecticut, Delaware, Maryland, Massachusetts, New York, Pennsylvania, Virginia, and West Virginia. The rest of the states were grouped into a Midwest (MW) states group: Iowa, Kentucky, Minnesota, Missouri, Wisconsin, and Nebraska.

Table 34 shows the best models found to estimate FTG in weekly deliveries, and FG in weekly pallets for each state or group of states. As shown, only two out of six case studies have an FG dependent on business size. For Michigan, the best way to represent FG and FTG is using a trip rate per employee. In the case of Ohio, the best way to represent FG and FTG is to use an OLS model comprised of a constant generation and a term, depending on the number of employees when the store is located off-mall. For the remaining of the cases, the best way to calculate trip generation is to apply a coefficient per establishment that varies between 0.950 and 1.636 trips. Similarly, the best way to estimate FG is to apply a coefficient per establishment that varies between 8.862 and 11.364.

The state attracting the most freight trips and pallets per store is Illinois. On the other hand, Ohio is the state attracting the smallest amount of freight trips and pallets per store. These results are hard to extrapolate because they only repre-

Copyright National Academy of Sciences. All rights reserved.

Table 34. Freight generation and freight trip generation by state for furniture store chain.

State	Obs.	Const.	Empl.	Empl. off mall	Avg. Del/est	Avg. Del/emp	Best Model	RMSE
		c	b1	b2				
TRIP GENERATION BY STATE								
ILLINOIS	11	1.636			1.636	0.148	S	1.1
OHIO	14	0.950		0.074	1.214	0.130	C	1.175
MICHIGAN	7		0.179		1.286	0.179	E	1.263
INDIANA	6	1.000			1.000	0.137	S	1.297
NEMA	6	1.000			1.000	0.111	S	1.302
MW	14	1.143			1.143	0.088	S	1.226
FREIGHT GENERATION BY STATE								
ILLINOIS	11	11.364			11.364	0.956	S	10.696
OHIO	14	8.862		0.619	11.071	1.143	C	10.433
MICHIGAN	7		1.690		12.143	1.690	E	11.262
INDIANA	6	9.833			9.833	1.343	S	11.598
NEMA	6	9.167			9.167	1.004	S	11.671
MW	14	10.857			10.857	0.862	S	10.899

Table 35. Freight trip generation by location of furniture stores.

Location	Obs.	Const.	Empl.	Combo store	Avg. Del/est	Avg. Del/emp	Best Model	RMSE
		c	b1	b2				
TRIP GENERATION BY LOCATION								
IN-MALL	31	0.793	0.039		1.161	0.115	C	1.051
OFF-MALL	27	1.182		0.818	1.333	1.128	C	0.909
FREIGHT GENERATION BY LOCATION								
IN-MALL	31	10.160			10.160	0.996	S	9.648
OFF-MALL	27	11.794			11.704	1.099	S	8.417

sent a biased sample of furniture stores, and these models are valid only for this specific sample. An important characteristic of the furniture chain studied is that it is a franchise. Being a franchise, the stores only receive deliveries from the mother warehouse as decided by the franchisor. Moreover, as there is just one distribution center, the number of trips attracted and the cargo attracted depend not only on the characteristics of the store, but specially on the logistic decisions made by the franchisor. This is not the case when a store receives deliveries from various suppliers.

In terms of land use, the only observable dimension for the sample collected was the location of the store. The LBCS developed by the APA[7] uses the structure dimension to differentiate in-mall locations and off-mall locations. The aim of the present research is to test the assumption that structure type (as defined by the LBCS) is a statistically significant factor in FG and FTG. The methodology adopted is based on OLS analyses.

As well as for the states' classification, standard trip generation rates and regression analyses were analyzed using store location (in-mall -M- or off-mall –OM) as a categorical factor to determine FG and FTG.

As shown in Table 35, the best way to represent attracted freight is by applying a constant trip generation per store; approximately 10 pallets attracted weekly in-mall-based locations and 12 in off-mall-based locations. In terms of FTG, Table 35 also shows that an off-mall locations' attraction depends on the nature of the store. Each conventional store and each outlet store located off-mall attracts approximately one weekly trip, while each combo store located off-mall attracts two trips weekly. A surprising finding is that the number of trips attracted by mall-based stores depends on the store size, which was not the case for the number of pallets attracted. This may reflect the different sales levels for the in-mall stores.

In addition to the models using each state and location type as a factor, the team estimated models for the pooled data. Specifically, the analyses focused on estimating models that

[7] More detailed information can be found in http://www.planning.org/lbcs/

Copyright National Academy of Sciences. All rights reserved.

Table 36. Freight trip generation model for pooled data (employment, store characteristics, location and state) for furniture stores.

Variable	Name	Coefficient	*t*-value
Regression model			
Intercept	CONSTANT	1.097	23.201
Store characteristic			
Combo store	COMBO	0.903	7.031
State and employment			
Employment in Michigan	EM_MICH	0.040	2.363
Observations	58		
F	25.770		
Adjusted R^2	0.470		

Table 37. Freight generation model for pooled data (employment, store characteristics, location and state) for furniture stores.

Variable	Name	Coefficient	*t*-value
Regression model			
Intercept	CONSTANT	10.420	19.329
Store characteristic			
Outlet	O	3.330	2.294
Observations	58		
F	5.260		
Adjusted R^2	0.070		

expressed the number of deliveries received, and the number of pallets received, per week, as a function of company attributes such as employment, geographic location and characteristics, and the interactions between these attributes. Table 36 shows the best models found to estimate trip generation using the pooled data, while Table 37 shows the results for the number of pallets attracted by store using the pooled data.

As shown in Table 36, trip generation varies according to the type of store, i.e., combo stores have a statistically significant higher attraction. Each combo store attracts 0.903 more trips every week than conventional or outlet stores, *ceteris paribus.* Additionally, as expected from the results shown in Table 34, trip attraction in Michigan depends on business size.

In contrast to the findings on trip generation, outlet stores were found to have different patterns of FG. As shown in Table 37, each conventional or combo store attracts 10.42 pallets weekly (constant), while each outlet store attracts 13.75 pallets weekly (constant + outlet stores coefficient). According to this model, the number of pallets attracted depends on the store type, but does not depend on employment. It is noteworthy that this model has a poor statistical fit.

NYC Receivers and Carriers Case: A Comparison Between Production and Attraction Activities Using Industrial Classification Systems (SIC and NAICS)

Freight Trip Attraction

Freight trip attraction refers to the number of truck trips attracted by an establishment as a result of its economic activity. Freight trip attraction is captured in the receivers surveys with the average number of deliveries received by each establishment in a typical day. Considering business size and industry sector, estimated models are discussed herein.

Standard Industrial Classification (SIC) System

The first step in the estimation process was to aggregate the different industries (2-digit) into broader groups according to their economic sectors. Using the SIC codes, 11 categories or groups were created. Eight of them were selected as freight-related and used in the estimation process: agriculture, forestry, and fisheries (Group 1); mineral industries (Group 2); construction industries (Group 3); manufacturing (Group 4); transportation, communication, and utilities (Group 5); wholesale trade (Group 6); retail trade (Group 7); and food (Group 8). The other categories: finance, insurance and real estate; service industries; and public administration were not considered in the model estimation process because they are not freight-related, and there was not enough freight trip information available.

For estimation purposes, the team used SICs which contained five or more observations in the OLS analysis. Table 38 shows the final models estimated for freight attraction. It is important to note that for groups 1 and 2 not enough information was available. Considering their relation to the industries in group 3, the delivery rate of group 3 is recommended for groups 1 and 2. For the case of group 5 (there were no observations) a constant rate of one delivery per establishment per day was assumed.

As shown in Table 38, more than half (53%) of the models are constant rates per establishment (Type S), 28.6% are linear models with an intercept and slope (Type C), and the other 19% depend on business size (Type E). Table 91 in Appendix I shows the type of resulting model for the different SICs and groups. More than half of the resulting models were constant per establishment (Type S) models; therefore, business size alone may not always be a good indicator of freight trip attractions.

The MCA is another estimation technique; it computes coefficients for each category of the predictors (e.g., employ-

Copyright National Academy of Sciences. All rights reserved.

Table 38. SIC—final models selected for freight trip attraction (deliveries/day).

Gr.	SIC	Description	Obs.	Const. / Empl. c	Const. / Empl. b	Best Model	RMSE
3	15, 16, 17	Construction*	25	2.160		S	0.869
	15	General contractors & operative builders	7		0.129	E	0.938
	17	Special trade contractors	17	2.106		S	1.365
4	21-39	Manufacturing*	45	3.156		S	3.420
	23	Apparel & other finished products	7	3.571		S	1.178
	24	Lumber & wood products, except furniture	5		0.067	E	0.764
	25	Furniture & fixtures	6	2.167		S	1.067
	34	Fabricated metal products	4	1.500		S	0.500
	39	Miscellaneous manufacturing industries	5	2.280		S	0.280
6	50, 51	Wholesale Trade*	117	2.272	0.069	C	3.655
	50	Wholesale trade - durable goods	58	3.986		S	4.740
	51	Wholesale trade - nondurable goods	59	1.713	0.071	C	2.147
7	52, 53, 55, 56, 57, 59	Retail Trade*	84	3.371		S	5.384
	52	Building materials... & mobile home dealers	9		0.369	E	1.672
	56	Apparel and accessory stores	13		0.187	E	4.598
	57	Home furniture, furnishings, equipment stores	13	3.769		S	2.189
	59	Miscellaneous retail	47	3.349		S	4.067
8	20, 54, 58	Food*	83	1.826	0.090	C	4.813
	20	Food and kindred products	3	2.000		S	0.032
	54	Food stores	23		0.288	E	4.851
	58	Eating and drinking places	56	1.307	0.081	C	3.091

**Group models*

ment and SIC). The coefficients are estimated in such a way that they provide the best possible fit to the observed data (i.e., minimize sum of squared errors). Type of disaggregate model (i.e., S, E, or C) and number of observations were the two factors used to group the industry segments. Given that employment was considered as the independent variable, only industries that exhibited a dependence on business size, based on the results of the OLS analysis (i.e., E or C), were considered.

Table 39 shows the MCA coefficients for freight attraction using SIC as the industrial classification system. Five bins with an interval width of 10 employees were used in the analyses; however, the results revealed what seem to be anomalous results for establishments within the 31–40 employee bracket. This reflects the low number of observations in that range. Therefore, the trip rates generated for employment above 30 were excluded from the analysis. This exclusion does not impact the significance of the analysis because over 90% of the businesses in the sample area (Manhattan and Brooklyn) have less than 30 employees (U.S. Census Bureau 2010b).

Since the models are employment dependent, as anticipated, the number of deliveries increases with employment. In general, establishments in the building mate-

Table 39. Multiple classification analysis results for sic for freight attraction (deliveries/day).

SIC								
Type of Model		Type E Models					Type C Models	
Industry Sector		Building construction	Lumber Wood	Building Material	Food Stores	Apparel & Accessories	Wholesale - durable goods	Eating and Drinking Places
Employees	1-10	1.405	n/a	3.648	3.768	1.176	1.984	1.875
	11-20	1.608	n/a	3.852	3.972	1.379	3.076	2.966
	21-30	6.550	4.274	8.794	8.914	6.321	4.466	4.356
RMSE		1.130	2.832	2.290	4.875	4.382	2.060	3.300

Copyright National Academy of Sciences. All rights reserved.

Table 40. NAICS—final models selected for freight trip attraction (deliveries/day).

Gr.	NAICS	Description	Obs.	Const. / Empl. c	Const. / Empl. b	Best Model	RMSE
1	23	Construction*	25	2.160		S	1.364
2	31, 32, 33	Manufacturing*	51	2.831		S	2.791
	31	Food, Beverage, Tobacco, Textile, Apparel, Leather & Allied Product Manufacturing	21	2.400		S	1.295
	32	Wood, paper, printing, petroleum & coal products, chemical, plastics, nonmetallic & mineral product manufacturing	10	4.420		S	5.483
	33	Metal, machinery, computer, electronic, electrical, transportation, furniture & misc. manufacturing	20	2.490		S	2.483
3	42	Wholesale Trade*	117	2.272	0.069	C	3.655
4	44, 45	Retail Trade*	98	3.070	0.063	C	4.054
	44	Motor vehicle, furniture, electronics, building material, food & beverage, health, gasoline, & clothing stores	69	2.458	0.132	C	4.298
	45	Sporting goods, hobby, book, & music stores	29	2.724		S	4.352
6	72	Accommodation and Food*	56	1.307	0.081	C	3.091

* Group models

rials and hardware industry (SIC 52) and food stores (SIC 54) receive, on average, approximately two more deliveries per day than those in building construction (SIC 15) and apparel and accessories (SIC 56) industries; both of which have similar freight attraction patterns. Food stores (SIC 54) also receive almost twice the amount of deliveries than establishments in the lumber wood (SIC 24); eating and drinking (SIC 58); and wholesale trade—nondurable goods (SIC 51) industries, except for establishments with 11–20 employees.

North American Industry Classification System (NAICS)

This section discusses the estimated FTG models considering NAICS as the industry classification system. Table 40 shows the final disaggregate models from the OLS analysis. As shown, 60% of the models are constant FTG rates per establishment (Type S), with the remaining 40% being combined models with intercept and slope (Type C). These results confirm the previous finding that business size alone may not be a good indicator of freight trip attraction.

The MCA models generated using NAICS for the receivers sample can be found in Table 41. It is worth noting that no models were solely dependent on number of employees (Type E); all the industries were represented by combined models (Type C). The results indicate that retail trade (NAICS 44) establishments, on average, receive one more delivery than those in wholesale trade (NAICS 42) and accommodation and food service (NAICS 72) industries; with the two latter industries having a similar FTG pattern.

Freight Trip Production

Freight trip production refers to the number of truck trips produced by the source of the commodities, i.e., the shipper. This is captured in the carriers' surveys with the average number of trips made by each establishment in a typical day. Considering the industry sector and the size of the business, estimated models are discussed in the following sections.

Standard Industrial Classification (SIC) System

The modeling process undertaken using the carriers dataset followed the same methodology as the receivers. The resulting OLS models using SIC coding are shown in Table 42. Approximately 42% of the models are of Type S, 33% are Type E, and 25% are Type C. The largest percentage of models estimates deliveries per establishment (Type S), which indicates that, as

Table 41. Multiple classification analysis results for NAICS for freight trip attraction (deliveries/day).

		NAICS		
Type of Model		C		
Industry Sector		Wholesale trade	Retail trade	Accomodation & food
Employees	1-10	2.443	3.543	1.902
	11-20	3.341	4.442	2.801
	21-30	5.685	6.785	5.144
RMSE		3.658	4.197	3.355

Copyright National Academy of Sciences. All rights reserved.

Table 42. SIC—final models selected for freight trip production (trips/day).

Gr.	SIC	Description	Obs.	Const. / Empl. c	Const. / Empl. b	Best Model	RMSE
3	15, 16, 17	Construction*	9		0.068	E	1.586
	17	Special trade contractors	8		0.065	E	1.576
4	21-39	Manufacturing	16	1.625		S	1.364
5	42, 47	Transportation, Communication and Utilities*	157	2.718	0.038	C	3.970
	42	Motor freight transportation & warehousing	148	2.764	0.035	C	3.850
	47	Transportation services	9		0.076	E	5.758
6	50, 51	Wholesale Trade*	126	1.944	0.036	C	5.408
	50	Wholesale trade - durable goods	65		0.059	E	3.628
	51	Wholesale trade - nondurable goods	61	4.328		S	6.939
7	52, 53, 55, 56, 57, 59	Retail Trade*	9	1.889		S	0.875
8	20, 54, 58	Food*	12	3.000		S	5.164
	20	Food and kindred products	11	3.182		S	5.167

** Group models*

with the receivers, business size may not be a consistent indicator of FTG. Table 92 in Appendix I shows the different SICs and groups, arranged by model type.

Table 43 shows the MCA results for the carriers sample for SIC. As previously mentioned, MCA is performed on models that depend on business size. The table shows the MCA results with an employment distribution of five bins, and with an interval width of 20 employees. Unlike with the receivers' sample, which had a consistent dip in the 31–40 employees bin, the carriers sample had some variations that were corrected using interpolation. The decrease in the number of deliveries might be related to a change in logistic decisions. However, this could also be a consequence of biased data for these specific bins in the studied sample. Further research needs to be done to better understand the FTG patterns for establishments with these employment levels.

MCA results for SICs show that establishments in the transportation services industry (SIC 47), on average, generate one more delivery than establishments in the construction (SIC 17) and wholesale trade durable goods (SIC 50) industries; while the two latter SICs have similar FG patterns. Establishments in the motor freight transportation and warehousing (SIC 42) industry had the highest trip rates among the SIC models in all but 21–40 and 41–60 bins, with the most notable being between 41–60 employees, where the trip rate was at least half the number of all the other employment dependent SIC models.

North American Industrial Classification System (NAICS)

Table 44 shows the final disaggregate models for the estimated freight trip production using NAICS as the industry classification. The results for NAICS indicate that 30% are Type S, another 30% were Type E, and the remaining 40% were Type C models, as shown in Table 44.

Table 43. Multiple classification analysis results for SIC for freight trip production (trips/day).

SIC					
Type of Model		Type E Model			Type C
Industry Sector		Special Trade Contractors	Transportation Services	Wholesale - durable goods	Motor freight transportation
Employees	1-20	1.448	2.863	1.641	3.346
	21-40	2.081	3.497	2.274	4.064*
	41-60	4.882	6.297	5.075	4.782*
	61-80	5.888*	7.303*	6.081*	5.500
	>80	6.894	8.309	7.086	9.750
RMSE		1.964	4.897	3.536	5.101

* Coefficients have been modified for consistency using interpolation

Copyright National Academy of Sciences. All rights reserved.

Table 44. NAICS—final models selected for freight trip production (trips/day).

Gr.	NAICS	Description	Obs.	Const. / Empl. c	Const. / Empl. b	Best Model	RMSE
1	23	Construction*	9		0.068	E	1.586
2	31, 32, 33	Manufacturing*	28	2.214		S	3.599
	31	Food, beverage, tobacco, textile, apparel, leather & allied product manufacturing	13	2.846		S	4.990
	32	Wood, paper, printing, petroleum & coal products, chemical, plastics, nonmetallic & mineral manufacturing	7		0.023	E	0.648
	33	Metal, machinery, computer, electronic, electrical, transportation, furniture & misc. manufacturing	8	1.750		S	1.639
3	42	Wholesale Trade*	124	1.755	0.036	C	5.094
4	44, 45	Retail Trade*	9		0.161	E	6.485
	44	Motor vehicle, furniture, electronics, building material, food & beverage, health, gasoline, & clothing stores	5	0.993	0.021	C	0.237
5	48, 49	Transportation and Warehousing*	157	2.718	0.038	C	4.811
	48	Air, rail, water, truck, transit, pipeline, scenic & sightseeing, & support activities	153	2.725	0.038	C	4.005

** Group models*

Table 45 shows the MCA results for the carriers' sample, for both SIC and NAICS. For the NAICS analysis, establishments in the construction (NAICS 23) industry averaged approximately one more trip than those in the manufacturing (NAICS 32) industry. Establishments in the transportation and warehousing (NAIC 49 and 48) industry both averaged at least one more trip than establishments in the retail trade (NAICS 44) industry.

Comparison Between Industrial Classifications Coding Systems

Table 46 shows the error metrics for the models estimated using NAICS industries as categorical factors. For each category, the table shows the error of applying the rates obtained from the models previously discussed. When FTG is constant, the delivery/trip rate per establishment found for the category is used; instead when FTG is employment dependent, MCA rates are used.

As shown, although SIC models perform slightly better when estimating freight trip attraction for the overall dataset with a RMSE of 3.49 compared to 3.56 for NAICS, the individual SIC industry models perform differently. Only manufacturing (NAICS 31) and retail trade (NAICS 44), two out of eight categories, show significantly better results for SIC models.

In contrast, NAICS models perform better than SIC models when estimating freight trip production, overall,

Table 45. Multiple classification analysis results for NAICS for freight trip production (trips/day).

NAICS						
Type of Model		Type E Models		Type C Models		
Industry Sector		Construction	Wood, paper, petroleum,coal, chemical, plastics manufacturing	Wholesale Trade	Motor vehicle, furniture, electronics, food & beverage retail	Transportation
Employees	1-20	2.424	1.303	2.946	1.685	3.381
	21-40	1.727	0.606	2.564	1.303	2.998
	41-60	2.061	0.939	3.283	2.023	3.718
	61-80	4.061	2.939	2.764	1.504	3.199
	>80	5.121	4.000	7.609	6.348	8.043
RMSE		1.074	0.934	4.650	0.618	5.219

Copyright National Academy of Sciences. All rights reserved.

Table 46. Model Estimation Errors (RMSE) for each Industry Segment (Freight Trip Production and Attraction).

Description	NAICS Code	Attraction		Production	
		RMSE (NAICS)	RMSE (SIC)	RMSE (NAICS)	RMSE (SIC)
Construction	23	1.364	1.275	1.074	1.859
Manufacturing	31	1.295	2.501	4.990	4.934
	32	5.483	5.568	0.934	1.051
	33	2.483	2.283	1.639	1.659
Wholesale Trade	42	3.658	3.655	4.650	4.895
Retail Trade	44	4.197	3.819	0.618	0.569
	45	4.352	4.396	8.539	10.551
Transportation & Warehousing	48	*	*	5.219	5.145
	49	*	*	2.018	2.009
Accommodation & Food	72	3.355	3.300	*	*
	Total	3.563	3.492	4.796	4.903

** No data available on the sample*

with RMSE of 4.80 for SIC compared to 4.90 for NAICS. Nevertheless, this performance is confirmed for only three out of nine categories, where the difference on the errors is larger than 10%. The industries where NAICS models give better freight trip production estimates are construction, manufacturing, and retail trade (NAICS 23, 32, and 45).

The analyses have highlighted the implications of the industry classification systems used when modeling FTG, though, results may be impacted by data limitations, industry comparability between the systems, and the resulting aggregations performed. As discussed, 2-digit industry aggregations were used for both SIC and NAICS, as there were not enough observations for a one-to-one mapping. An analysis of the different industries' definitions revealed that the closest match would have been to use a two-digit NAICS with the 2-digit SIC industries; however, this was not possible. Furthermore, FTG modeling efforts should use 3-digit NAICS and 2-digit SIC for higher level of detail, as these would allow an adequate trade-off between level of detail for disaggregate analyses and the number of observations to be collected.

NYC Receivers Case: A Comparison of Freight Attraction Between Local Land Use Codes and Universal Standard Land Use Codes

This section describes the FTG models developed based on two land use classification systems that are applicable to NYC. The first is the City of New York Zoning Resolution (NYCZR), developed in 1916 and updated regularly. The second is the LBCS, developed by the FHWA in partnership with the APA. These systems provide the basis for analyzing the effects of land use on FTG.

The City of New York Zoning Resolution (NYCZR)

Zoning ordinances adopted by municipalities regulate the size and use of land and buildings, including location and density. This is a key tool for carrying out municipal planning policy, along with the powers to budget, tax, and condemn property. In this context, NYC has been a pioneer in land use zoning since it enacted the nation's first comprehensive zoning ordinance.

The NYCZR classifies basic land uses including the three considered in this study: residential (R), commercial (C), and manufacturing (M). Within these classifications are subcategories for low-, medium- and high-density uses and/or buildings (e.g., "light" manufacturing, "single-family" residential). Although similar zoning designations may be aggregated into district classifications, e.g., residential, these districts may allow other uses, such as ground-floor commercial or "grandfathered" pre-existing non-conforming uses, such as auto repair shops. Recent zoning amendments favor "mixed use" classifications that include commercial, residential, and work space, to promote "walkable" communities. In essence, residential districts also generate freight (NYC Department of City Planning 2010).

As described in the NYCZR, districts are classified in ascending order of density or operations. For example, residential districts are classified R-1 through R-10, in ascending order of density, while manufacturing districts are classified M-1, M-2, and M-3 depending on characteristics and specific operations. Commercial districts are also classified numerically by allowable activities. For example, Central business district C-5 allows offices, high-end retail establishments, and continuous retail frontage, while C-6 allows corporate headquarters and large hotels (NYC Department of City Planning 2010).

For estimation purposes, the authors used NYCZR land use classifications with more than five establishments. Where

Copyright National Academy of Sciences. All rights reserved.

Table 47. Freight trip attraction by NYCZR land use and type of models.

Gr.	Land Use	Obs.	Const. / Empl. c	Const. / Empl. b	Avg. Del/est	Avg. Del/emp	Best Model	R^2 Adj.	RMSE
Commercial District	C1-9	8	4.900		4.900	0.090	S		6.007
	C5-2	9	2.670		2.670	0.076	S		1.414
	C5-3	22	3.509		3.509	0.089	S		3.448
	C5-5	7	2.343		2.343	0.163	S		1.401
	C6-6	6	2.200		2.200	0.072	S		1.633
	C1C4C5C6*	115	2.760	0.063	4.179	0.127	C	0.050	5.417
	C2C8*	7	4.286		4.286	0.137	S		3.692
Manufacturing District	M1-1	24	3.700		3.700	0.094	S		3.948
	M1-2	11	1.909		1.909	0.754	S		1.240
	M1-2/R6A	7	7.229		7.229	0.154	S		9.416
	M1-2D	7	3.057		3.057	0.135	S		1.841
	M1-6	31	1.287	0.069	2.271	0.121	C	0.135	1.926
	M3-1	32	3.381		3.381	0.122	S		2.935
	Manufact.*	138	3.216		3.216	0.115	S		4.000
Residential District	R6	20		0.338	4.740	0.338	E	0.498	3.496
	R6A	15		0.243	3.000	0.243	E	0.075	1.720
	R6B	13	5.415		5.415	0.248	S		8.624
	R7-1	5	1.960		1.960	0.073	S		1.795
	R7-2	5		0.206	4.200	0.206	E	0.248	2.596
	R7A	14		0.140	3.786	0.140	E	0.101	4.647
	R8	10	2.660		2.660	0.125	S		1.470
	Resid.*	10	2.660		2.660	0.125	S		4.427
	Total								4.460

some land uses had five or fewer, the individual classes were aggregated. For a more detailed description about grouping procedures, see (Holguín-Veras et al. 2011). For example, commercial establishments were divided into two groups: retail and service oriented establishments.

Trip generation rates and linear regression models were estimated for various land use categories. Table 47 shows the final models estimated for freight trip attraction in the disaggregated land uses, and in the land use groups (i.e., C1C4C5C6, C2C8, Manufacturing, and Residential). All of the variables presented on the tables were found to be significant at the 95% confidence level.

The best models were selected based on t-statistics and RMSE. The results indicate that for 73% of the FTG models, a constant coefficient produces the best results; for 18% of the models, FTG depends on employment; and for 9% FTG is a combined model, with a constant coefficient plus an employment term. The results also indicate that employment dependent models (type E) are found in residential classifications with moderate- and high-density districts (R6, R6A, R7-2, R7A), while FTG in light manufacturing land use (M1-6) is better represented by a combined model (type C). For the remaining land uses, especially commercial land use, FTG is better represented by a constant coefficient.

The next step was to conduct MCA analyses for those land use classifications with FTG that depend on employment (types E and C). The rates found were conceptually valid for establishments with less than 30 employees, but exhibited anomalies in the group of 31–40 employees. This likely results from the lack of a sufficient number of observations in the 31–40 employees group to support the MCA estimation. (The number of observations in this range was significantly smaller than for the other groups). For that reason the 31–40 employees group was omitted from the analysis. This omission does not affect the relevance of the research because (as previously discussed) more than 90% of the establishments in Manhattan and Brooklyn have fewer than 30 employees. More research is needed to explain FTG patterns on establishments with more than 30 employees.

Table 48 shows the FTG rates for NYCZR land uses for different employment levels.

Table 48. MCA results for daily freight trip attraction by the city of New York Zoning Resolution (NYCZR) land uses.

		NYCZR C6*	M1-6	R6	R6A	R7-2	R7A	R*
Employees	0-10	2.97*	1.49	3.28	2.37	0.95	1.14	2.73*
	11-20	3.53*	2.25	4.38	3.47	2.05	2.24	3.28*
	21-30	6.10*	5.67	8.33	7.42	6.00	6.19	5.86*
RMSE		5.380	1.670	3.240	1.990	2.450	4.560	4.390

*Notes: (1) Overall RMSE: 4.430 (2) *Based on group models*

Copyright National Academy of Sciences. All rights reserved.

Table 49. Freight Trip Attraction by LBCS Function.

Gr.	LCBS	Obs.	Const. / Emp. c	Const. / Emp. b	Avg. Del/est	Avg. Del/emp	Best Model	R^2 Adj.	RMSE
Function	Retail	73	3.682		3.682	0.140	S		5.111
	Grocery	24		0.217	5.225	0.217	E	0.039	5.280
	Pharmacy	16	3.988		3.988	0.203	S		3.469
	Food	55	1.307	0.081	3.100	0.111	C	3.147	3.092
	Textiles	12	2.867		2.867	0.153	S		1.459
	Miscellaneous 1	26	3.254		3.254	0.094	S		4.081
	Durable Goods	60	4.387		4.387	0.173	S		5.736
	Nondurable Goods	54	1.681	0.072	2.948	0.121	C	2.256	2.214
	Miscellaneous 2	32	3.919		3.919	0.118	S		6.871
	Total								4.622
Activity	Goods	265	2.588	0.067	3.811	0.141	C	4.583	4.565
	Services	34	3.865		3.865	0.117	S		6.670
	Restaurant	16	2.488		2.488	0.149	S		1.939
	Other	1	0.400		0.400	0.080	S		N/A
	Plant	38	3.132		3.132	0.100	S		3.483
	Total								4.620

Land-Based Classification Standards (LBCS)

This section discusses the models estimated for NYC using the LBCS, and specifically, the factors most relevant for the purposes of FG: LBCS Function and LBCS Activity. Table 49 shows the final models estimated for freight attraction.

The results indicate that for 67% of the FTG LBCS Function models, a constant coefficient produces the best results; for 11% of the models, FTG depends on employment; and for 22% of the models, FTG is a combined model, with a constant coefficient plus an employment term (for LBCS Activity, this breakdown is 80%, 0%, and 20%, respectively).

MCA models were estimated for the LBCS Function classifications in which FTG depends on employment. As in the previous section, there is an abnormal coefficient for establishments with 31–40 employees; therefore, these establishments were omitted from the results shown in Table 50.

Table 50. MCA for freight trip attraction by LBCS function land uses.

		Grocery	Food	Non Durables
Employees	0-10	4.13	1.86	1.92
	11-20	5.44*	2.96	3.02
	21-30	6.75	4.38	4.44
RMSE		5.032	3.301	2.120

*Notes: (1)*Coefficient has been modified for consistency*
(2) Overall RMSE: 4.600

Comparison Between LBCS and NYCZR

Upon analysis, the authors found that for both NYCZR and LBCS, most of the best models were produced using a constant coefficient only, and do not depend on business size (quantified as number of employees). When using NYCZR, land use classifications as the categorical factor, 73% of the land uses were best estimated when a constant coefficient is used. Similarly, when using LBCS Function as the categorical factor, six out of the nine land use categories were best estimated using a constant coefficient. When LBCS Activity is used as the categorical factor, four out of the five land use categories were best estimated using a constant coefficient. These results are consistent with the findings when using the industry segment as the categorical factor as described in Holguín-Veras et al. (2011). The evidence of non-employment dependent FTG for most land uses and establishments in NYC is indeed convincing.

The regression model results indicate the RMSE is 4.46 for NYCZR and 4.62 for LBCS (see Tables 47 and 49); while the MCA models leads to RMSE of 4.43 for NYCZR and 4.60 for LBCS (see Table 48 and Table 50). This indicates that MCA performs slightly better than regression analysis for almost every land use classification where FTG is employment dependent, even though it is a very small difference with respect to the overall error. This is not surprising, because MCA has more degrees of freedom than regression analysis, at the expense of higher data requirements.

In essence, where FTG is constant, employment plays no role. Table 51 summarizes the best FTG coefficients for the

Copyright National Academy of Sciences. All rights reserved.

Table 51. Summary of daily freight trip attraction by land use, New York City.

NYCZR						LBCS	
Land Use	Trips/ Establishment	Land Use	Trips/ Establishment	Land Use	Trips/ Establishment	Land Use	Trips/ Establishment
C6-6	2.20	M1-2	1.91	R7-1	1.96	Textiles	2.87
C5-5	2.34	M1-2D	3.06	R8	2.66	Misc. 1	3.25
C5-2	2.67	M1*	3.14	R6B	5.42	Retail	3.68
C5*	3.17	M2*	3.22			Misc. 2	3.92
C5-3	3.51	M3-1	3.38			Pharmacy	3.99
C2*	4.29	M3*	3.38			Durables	4.39
C8*	4.29	M1-1	3.70				
C4*	4.86	M1-2/R6A	7.23				
C1-9	4.90						
C1*	5.03						

*Use this group coefficient when no detailed land use coefficient is found

a) Constant trip attraction per establishment

		NYCZR							LBCS		
		C6*	M1-6	R6	R6A	R7-2	R7A	R*	Grocery	Food	Non Durable
Employees	0-10	2.97	1.49	3.28	2.37	0.95	1.14	2.73	4.13	1.86	1.92
	11-20	3.53	2.25	4.38	3.47	2.05	2.24	3.28	5.44	2.96	3.02
	21-30	6.10	5.67	8.33	7.42	6.00	6.19	5.86	6.75	4.38	4.44

*Use this group trip rate when no detailed land use coefficient is found

b) Trip rates per establishment by employment size

NYC study dataset. Cities with characteristics analogous to NYC, especially Manhattan and Brooklyn, or with similarly situated neighborhoods, may have similar FTG patterns, in which case the findings of this report could be extrapolated. However, it is important to emphasize that the results found are valid only in the context of this dataset.

The next step of the analyses compared the performance of models using local zoning classifications (NYCZR) with models using a standardized classification system such as the LBCS. The RMSE analysis, performed on the complete dataset using the best models for each land use classification (including models for pooled data and grouped land uses) found that the overall error for NYCZR was 4.21, as compared to 4.53 for LBCS. According to this RMSE analysis, classifying land uses using NYCZR gives more accurate results for a local dataset, which is not surprising. The reason is related to the data limitation (i.e., the high level of correlation between LBCS dimensions) that prevents taking advantage of the multiple dimensions of the LBCS.

Although LBCS was not found to be superior to the NYCZR, it is not possible to make definitive conclusions about LBCS merits for FTG modeling. In fact, it is only through the use of LBCS that intercity comparisons can be made and the potential exists for universal or transferable FTG models. To assess the potential of LBCS will require applying and comparing results to other local land use classifications (e.g., Seattle, WA, or Portland, OR).

Comparison Between Institute of Transportation Engineers and Land Use Models

This section compares the performance of the models based on NYCZR and LBCS with the current benchmark in this field of study, The Institute of Transportation Engineers (ITE) *Trip Generation Manual.* The ITE has produced a series of manuals to estimate the number of vehicle trips generated by a facility or establishment located in a particular "land use." The latest version of this manual is the 8th Edition (Institute of Transportation Engineers, 2008). In this manual, trip generation rates are provided based on trip generation studies submitted to ITE by public agencies, consulting firms, universities, developers, and others. These include average freight truck trips for several categories of land use, including truck terminals, industrial parks, warehouses, mini warehouses, high-cube ware-

Copyright National Academy of Sciences. All rights reserved.

Table 52. Estimation errors (RMSE) for freight trip attraction models by land use classifications.

ITE land use	NYC Sample		ITE employment models		NYCZR		LBCS	
	Trip Attraction	Establish-ments	Trip Attraction	RMSE*	Trip Attraction	RMSE*	Trip Attraction	RMSE*
Hardware/Paint Stores	60	8	43	4.1	36	4.4	35	4.8
Wholesale Markets	823	102	1527	15.9	659	12.9	791	12.9
Furniture Stores	51	14	42	6.4	99	5.9	63	5.7
Total	934	124	1612	14.6	794	11.9	889	11.9

*RMSE is computed at the establishment level

houses, assisted living facilities, state departments of motor vehicles, United States post offices, research and development centers, free standing discount stores, hardware/paint stores, wholesale markets, furniture stores, and quality restaurants.

The research, to ensure comparability, focused on those establishments present in both the ITE Manual and the NYC dataset: hardware/paint stores, wholesale markets, and furniture stores. In some cases, ITE models do not consider a specific directionality for freight trips. As there is not enough information in the ITE Manual, the authors assume that truck trips are a fraction of total vehicle trips, in which case freight-related trips entering and leaving the establishments would be the same proportion as passenger trips. This is not the case for the models developed in this study, as the NYCZR and LBCS only estimate freight trip attraction (in terms of deliveries). As any delivery attracted by an establishment produces two trips (one loaded, entering the establishment, and one empty, leaving), each delivery is multiplied by two to obtain the total number of trips attracted. Future research will focus on freight trip production.

Table 52 compares the RMSE for the establishments located in the specific land uses that can be classified in all three: NYCZR, LBCS and ITE. If high employment establishments are included in the analysis, RMSE increase substantially.

In general, NYCZR and LBCS models perform better than the ITE rates. Table 52 shows that the overall RMSE is usually larger for ITE models than for the land use models developed in this study. For furniture stores and hardware/paint stores, the models have a similar performance. For wholesale stores, which account for 82% of the sample, NYCZR and LBCS models have a superior performance (i.e., RMSE is 18% lower). When considering the complete sample, the total RMSE of NYCZR and LBCS models is about 30% lower than ITE's. In essence, the models developed in this research give more accurate estimates for trip attraction.

Area-Based Models

As found in the review of the freight systems and land use, there are variables that play a significant role in the estimation of FTG. For example, the previous sections have shown the estimated disaggregate models for FTG based on employment for different industry segments and land use categories. Given that the estimated models are based solely on employment (due to limited data availability, and despite team efforts to include area as independent variables for the case study datasets), it was also important to understand the relationship between FTG and the establishments' areas.

To estimate the relationship between employment and area, two different datasets were used. On one hand, merging the Tax-Lot Polygon Feature Class of the Department of Finance's Digital Tax Map with the 2006 PLUTO™ attribute data for NYC—defined as the attribute table of property information associated with each tax lot[8]—provided aggregated estimates of the establishments' areas. In general, the PLUTO™ data files contain three basic types of data: tax lot characteristics; building characteristics; and geographic/political/administrative districts. The dataset also contains information about different types of tax lot areas (see Table 93 in Appendix I).

On the other hand, the County Business Patterns provided data on the total number of establishments, employment, first quarter and annual payroll, and number of establishments by nine employment-size classes by detailed industry for all counties in the United States, the District of Columbia, Puerto Rico, and the Island Areas (American Samoa, Guam, Northern Mariana Islands, and Virgin Islands)[9]. Information for only NYC was used for the analyses.

After the two datasets were assembled, aggregates at the ZIP code level of employment, number of establishments, and the different areas were estimated. Linear regression

[8]http://www.nyc.gov/html/dcp/html/bytes/applbyte.shtml
[9]http://censtats.census.gov/cbpnaic/cbpnaic.shtml

Copyright National Academy of Sciences. All rights reserved.

Table 53. Employment and number of establishments vs. area models.

	Independent Variable	Area Coefficient*	Adjusted R^2
Building Area	employment	1.41E-03 (12.51)	0.77
	number of establishments	6.70E-05 (25.19)	0.82
Commercial Area	employment	2.47E-03 (25.19)	0.92
	number of establishments	1.10E-04 (16.44)	0.85
Residential Area	employment	1.90E-03 (4.70)	0.33
	number of establishments	1.04E-04 (6.11)	0.48
Office Area	employment	3.86E-03 (19.51)	0.88
	number of establishments	1.63E-04 (11.02)	0.73
Retail Area	employment	2.21E-02 (13.13)	0.79
	number of establishments	1.06E-03 (16.59)	0.85

models using employment or number of establishments per ZIP code as dependent variables, and the different areas as independent variables, were estimated. Table 53 shows the resulting models. Users can choose the best type of model depending on the available area information. The adjusted R^2 value generally exceeds 0.60. As expected, there is no significant relation between residential area and employment or number of establishments as shown by the low R^2. With these models, the number of employees can be estimated from area aggregates, which allows the user to implement the FTG models discussed in previous sections.

Application of Synthetic Correction

This section discusses the theoretical background of synthetic correction and explains the need for this procedure to adjust some of the models found in the literature. The objective of this procedure is to correct existing models to account for the differences in FTG patterns for both small and large establishments. In fact, the empirical evidence from the FTG models estimated with establishment-based data indicates that FTG rates depend on business size. As discussed, small establishments tend to generate proportionally more trips than large establishments. This leads to a situation in which a constant trip rate underestimates the FTG of small establishments and overestimates the one for large businesses. This poses a problem because several FTG models reported in the literature are in the form of constant trip rates.

Figure 12 shows an example of an establishment-based FTG model estimated with data collected by the team. Two different models are shown. The first model is the constant trip rate model that goes through the origin; while the second is the regression model with an intercept and a slope. The theory of OLS (regression) indicates that both models intercept each other, exactly at the midpoint of the data (at the average values of the independent and dependent variables).

The fact that both models intercept at the midpoint $(\bar{X}, \bar{Y})$ provides the basis for a simple correction procedure. For those industry segments expected to follow the FTG pattern with an intercept and a slope, and for which constant trip rates are available, the synthetic correction procedure is:

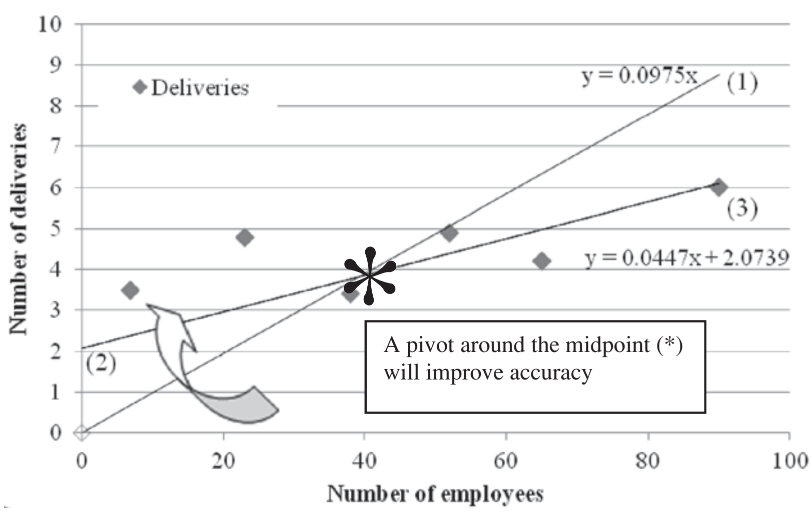


Figure 12. Constant freight trip generation rate model vs. regression model with intercept.

Copyright National Academy of Sciences. All rights reserved.

1. Use the constant trip rate and an estimate of the average business size ($\bar{X}$) to compute the average trip generation ($\bar{Y}$) as:

$$\bar{Y} = Rate * \bar{X} \tag{4}$$

2. Estimate the number of trips produced by a small (less than five employees) business in the same industry sector (c′).
3. Assuming that c′ is equal to the intercept of the model, compute the slope of the straight line connecting the intercept (0, c′) and the average case ($\bar{X}$, $\bar{Y}$) as:

$$b = \left(\bar{Y} - c'\right)/\bar{X} \tag{5}$$

The equivalent model is:

$$Y = c' + bX \tag{6}$$

The key element here is that, although an approximation, even a suboptimal assumption of the intercept is bound to perform better than the constant trip rate model. In the case shown in Figure 12, for instance, an assumption that the intercept is equal to one could reduce the total error with respect to the constant trip rate model by almost half. This improvement in the model performance definitely shows the potential of using this technique. Various models found in the literature are corrected in Table 54 with an aim to account for the difference in employment proportionality of business with different sizes.

As shown, FTG models that use an employment trip rate benefit from a correction. The first step is to identify the models in the literature that can be corrected and used. Out of the 1,024 FTG models found in the literature and included in the database, only 241 are estimated as a function of employment. The techniques used to estimate these models are OLS or simply trip rates. 107 out of the 241 employment dependent models were computed using OLS technique. In the other cases, FTG is calculated as a rate of employment. For the latter models a synthetic correction is needed.

The correction proposed is based on the models by SIC estimated for the NYC case studies. As a result, it is only possible to correct models that have specifications similar to the ones developed. In essence, only the FTG models with employment dependency, and having a freight-related industry segment as categorical factor, or a land use, can be corrected. Moreover, the dimension of the dependent variable must be truck trips; multi-class models were not available and therefore not estimated. Some models were excluded from the correction procedure because they did not specify whether they are for trip attraction or for production. Finally, only 29 out of the 134 trip rates were selected for correction. Table 54 shows the models selected for correction. As shown, the source number and case study number codification enables the reader to locate these models in the FG/FTG model relational database developed by the team.

As shown in Table 54, the corrected models present conceptually valid coefficients. Only two cases were taken out because, after applying the synthetic correction, a negative slope was found. For the presented models, the intercept shows that small businesses produce between 1 and 4 daily truck trips. In terms of employment, the slope b represents the expected change in daily truck trips associated with a unit change in employment. For the models corrected, a unitary change in employment is associated with an increase in the number of daily truck trips that varies from 0.05 to 2.5. According to previous findings, the models where the employment parameter presents values higher than 0.5 tend to overestimate FTG for large establishments.

Seattle Region and Manhattan Grocery Stores: A Comparison of FTG Patterns Across Regions

This section gives the results from the analyses conducted by company freight trip attraction from a sample of grocery stores in Manhattan and the Seattle Region. In the case of Manhattan, grocery stores from the receivers sample were complemented with the information of the Whole Foods stores. The OLS method was used to estimate freight trip attraction. Table 55 shows the estimated model. As shown, a combined model with intercept and slope was obtained.

To compare the FTG patterns across regions, the effect of geographic location of the establishments in the attraction of deliveries was explored. In doing so, the research team combined the grocery store data from Manhattan and the Seattle Region and also created variables related to the geographic location (SOUPUGR and interaction term EMP_SPR). The model obtained is shown in Table 56. As shown, the geographic location variables are not statistically significant (low t-value) and the adjusted R^2 is low.

Furthermore, the estimated attraction models for the Manhattan sample were applied to the Seattle Region grocery stores. The industry-based model shown in Table 55 for Manhattan, and the LBCS Function model for grocery stores (0.217 deliveries per employee) shown in Table 49, were used. The estimated delivery trips for the Seattle Region are shown in Table 57. The observed deliveries per day are estimated as the average of the survey results and the two manual counts shown in Table 33.

Implications and Directions

Key implications and suggested directions are discussed next.

Copyright National Academy of Sciences. All rights reserved.

Table 54. Synthetic correction applied to models reported in the literature.

Source Number**	Case Study Number**	Industry Segment / Land Use	Trip Rate	Synthetic Intercept (c')	Synthetic Slope (b)
Production Models					
FTG-SYN-1996-1	RU-1992-1	Retail Trade (SIC 52-59)	1.21	1.89	1.13
FTG-SYN-1976	UT-1977-1	Urban Downtown Retail-Knoxville	2.30	1.89	2.23
FTG-SYN-1976	UT-1977-2	Urban Downtown Retail-Modesto	0.66	1.89	0.59
FTG-SYN-1976	UT-1977-3	Urban Downtown Retail-Rochester	0.12	1.89	0.05
FTG-SYN-1976	UT-1977-4	Urban Downtown Retail-Saginaw	0.30	1.89	0.23
FTG-SYN-1976	UT-1977-5	Urban Downtown Retail	0.40	1.89	0.33
FTG-SYN-1976	UT-1977-6	Urban Wholesale Operations-Knoxville	0.39	1.94	0.35
FTG-SYN-1976	UT-1977-7	Urban Wholesale Operations-Modesto	0.68	1.94	0.64
FTG-SYN-1976	UT-1977-8	Urban Wholesale Operations-Rochester	0.44	1.94	0.40
FTG-SYN-1976	UT-1977-9	Urban Wholesale Operations-Saginaw	0.28	1.94	0.24
FTG-SYN-1976	UT-1977-10	Urban Wholesale Operations	0.30	1.94	0.26
FTG-SYN-1976	UT-1977-11	Urban Wholesale Operations-Dallas	0.60	1.94	0.56
FTG-SYN-1976	UT-1977-12	Urban Truck Terminals-Knoxville	1.35	2.76	1.20
FTG-SYN-1976	UT-1977-13	Urban Truck Terminals-Modesto	1.63	2.76	1.48
FTG-SYN-1976	UT-1977-14	Urban Truck Terminals-Rochester	1.15	2.76	1.00
FTG-SYN-1976	UT-1977-15	Urban Truck Terminals- Saginaw	1.91	2.76	1.76
FTG-SYN-1976	UT-1977-16	Urban Truck Terminals	1.40	2.76	1.25
FTG-SYN-1976	UT-1977-17	Urban Truck Terminals- Dallas	1.42	2.76	1.27
Attraction Models					
FGTG-BK-1992-1	BA-1982	Manufacturing Firms	0.56*	3.16	0.42
FGTG-BK-1992-1	BA-1982	Construction Firm	1.92*	2.16	1.82
FGTG-BK-1992-1	BA-1982	Wholesale/Retail/Dealer Firm	2.62*	2.27	2.49
FTG-SYN-1996-1	RU-1992-1	Retail Trade (SIC 52-59)	1.21	3.37	0.98
FTG-SYN-1995-1	BR-1977-1	Grocery Wholesale Establishment	0.56	1.71	0.46
FTG-SYN-1995-1	BR-1977-1	Hardware Wholesale Establishment	0.32	3.99	0.09
FTG-SYN-1995-1	BR-1977-1	Other Wholesale Establishment	0.48	2.27	0.35
FTG-SYN-1995-1	BR-1977-1	Total Wholesale Establishments	0.50	2.27	0.37
FTG-SYN-1995-1	BR-1977-5	Furniture Establishments	0.48	2.17	0.41

*Notes: (1) *Rate was converted to daily trips dividing by 5 the original weekly rate*
*(2) **Models can be found in the Database of Task 7 using these codes*

Table 55. Manhattan grocery stores freight trip attraction model.

Variable	Name	Coefficient	*t*-value
Regression model			
Intercept	CONSTANT	5.731	2.133
Total employment	USEDEMPL	0.087	2.726
n (establishments)	31		
RMSE	4.92		
R^2	0.204		
Adjusted R^2	0.177		

Table 56. All grocery stores freight trip attraction model (NYC & Seattle Region).

Variable	Name	Coefficient	*t*-value
Regression model			
Intercept	CONSTANT	5.767	2.325
Total employment	USEDEMPL	0.087	2.938
Geographic Location	SOUPUGR	-9.505	-0.6468
Employ. Seattle Region	EMP_ SPR	0.811	0.528
n	38.00		
R^2	0.030		
Adjusted R^2	0.006		

Copyright National Academy of Sciences. All rights reserved.

Table 57. Estimated freight trip attraction for Seattle region grocery stores based on Manhattan models.

Store and Location	Emp.	Observed del/day	Estimated del/day using SIC model	Estimated del/day using LBCS Function: Grocery
QFC Wallingford	80	19	13	17
QFC Kirkland	70	14	12	15
QFC Mukilteo	70	15	12	15
QFC Capitol Hill	100	14	14	22
QFC Lynnwood	72	13	12	16
Albertsons Kent	60	14	11	13
PCC Issaquah	95	22	14	21
		RMSE	4.28	3.32

External Validity of FTG Models

The objective of an external validation is to assess the predictive ability of a statistical model. The motivation is that statistical methods make use of fitting routines that can lead to over-fitting or spurious fitting. In these cases, the FTG models may fit the data used for estimation, but they might not be predictive of FTG in a different context. To validate the models estimated in the previous section, a new collection data effort was performed in the Capital Region of New York State using the questionnaire form provided in Appendix H. The establishments surveyed provided information about daily FTG, employment, industry segment, service trips, and number of vehicles operated from the establishment, among others. Using the data collected from the establishments targeted, only the attraction models using SIC, NAICS, and LBCS as categorical factors can be validated. (The models using NYC Zoning Resolution as categorical factors cannot be validated with this data because NYCZR land use classification is exclusive for NYC.)

The goodness-of-fit (GOF) measure implemented to assess the statistical model performance on validation data was the Pearson Product-Moment Correlation Coefficients. This correlation coefficient denoted by r, measures the linear association between two variables Y1 and Y2 that have been measured on ratio scales.

The Pearson Product-Moment Correlation Coefficients is defined as:

$$r = \frac{\sum\left(Y_i - \bar{Y}\right)\left(\hat{Y}_i - \bar{\hat{Y}}\right)}{\left[\sum\left(Y_i - \bar{Y}\right)^2 \sum\left(\hat{Y}_i - \bar{\hat{Y}}\right)^2\right]^{1/2}} \qquad (7)$$

Where,

Y_i is the observed number of deliveries observed for each establishment on the external validation dataset,

Table 58. External validation using Pearson product-moment correlation coefficients—SIC & NAICS.

SIC/NAICS	Description	Obs	r
SIC 52	Building Materials	5	0.94
SIC 54	Food Stores	8	0.85
SIC 56	Apparel and Accessory Stores	8	0.94
SIC 58	Eating and Drinking Places	5	0.47
NAICS 44	Retail Trade	21	0.85
NAICS 72	Accommodation and Food	5	0.47

$\bar{Y}$ is the average of deliveries observed in the external validation dataset,

$\hat{Y}_i$ is the number of deliveries estimated using FTG models for each establishment on the external validation dataset, and

$\bar{\hat{Y}}$ is the average of deliveries estimated using FTG models for the external validation dataset.

A model predicting observed data perfectly produces a straight line plot between observed Y_i and predicted values $\hat{Y}_i$, and a correlation coefficient of 1.0. Conversely, linear correlation coefficients of 0 suggest no linear association between observed and estimated values. Table 58 and Table 59 present the results of this procedure.

As shown, for SIC 52 and SIC 56 (building materials and apparel/accessory stores) predicted and observed values for FTG have a linear correlation coefficient very close to one. For these industry segments, the models work the best according to the external validation. For food stores (SIC 54); retail trade (NAICS 44); retail trade (LBCS Function: Retail, LBCS Activity: goods); and grocery stores (LBCS Function: grocery) there is a linear correlation, which shows that these models are externally valid.

In terms of classifications related to restaurants (SIC 58; NAICS 72; LBCS Function: Food; and LBCS Activity: Restaurants) the Pearson Product-Moment Correlation Coefficients show that there is not a strong linear correlation between observed and estimated number of deliveries received. Therefore, restaurants and food service establishments are industry segments that need a closer examination when applying the models developed in this project to different contexts. An a priori conclusion might be that restaurants

Table 59. External validation using Pearson product-moment correlation coefficients—LBCS.

LBCS	Description	Obs	r
F. Retail	Function Retail	13	0.76
F. Grocery	Function Grocery	8	0.85
F. Food	Function Food Service	5	0.47
A. Goods	Activity Goods	21	0.63
A. Rest	Activity Restaurants	5	0.47

Copyright National Academy of Sciences. All rights reserved.

Table 60. *Quick Response Freight Manual* performance metrics-Pearson Product-Moment Correlation Coefficients.

SIC	Description	Obs	NYC Models: r	Phoenix Models: r
SIC 52	Building Materials	5	0.94	-0.66
SIC 54	Food Stores	8	0.85	0.85
SIC 56	Apparel and Accessory Stores	8	0.94	0.91
SIC 58	Eating and Drinking Places	5	0.47	0.47

have different logistic choices in big cities like NYC than in other urban/rural contexts.

Although the Pearson Product-Moment Correlation Coefficients provide metrics to measure objectively the performance of the models developed, measuring the performance of a benchmark model can set the basis for comparison. The *Quick Response Freight Manual* (U.S. Department of Transportation 1996) was chosen as the benchmark. The methodology proposed in this Manual uses SIC as a categorical factor, and estimates FTG using employment rates from a study in Phoenix, Arizona. While the approach in the *Quick Response Freight Manual* focuses on traffic generated by establishments, the models developed herein differentiate between freight trips attracted and freight trips produced. This refinement allows a different specification for productions and attractions, even when the establishments are in the same industry sector. For example, for building materials stores (SIC 52) trips attracted are better estimated using an employment rate, however trips produced are better estimated using a constant generation per establishment. This characteristic (of the models developed in this project) allows smaller aggregation errors. Table 60 compares the performance of the models developed in this project to the benchmark (Phoenix Models). The metric used for comparison is the Pearson Product-Moment Correlation Coefficients.

As shown, for most of the industry sectors, both models have a similar performance. However, for the building materials stores (SIC 52) NYC Models perform significantly better. As previously explained, for this type of establishment trips attracted are better estimated using an employment rate, while trips produced are better estimated using a constant generation per establishment. This difference is not considered in the Phoenix case study, producing a loss in the accuracy of the estimates.

Transferability of FTG Models

Considering the results and models found for the furniture store chain, both state location and store location play an important role as categorical factors. The question remaining is: Should one create new models by state, or estimate models based on land use characteristics (such as store location), ignoring transferability concerns? Accordingly a RMSE analysis was performed to assess the two alternatives. Table 61 shows the resulting estimation errors for the observations when applying the best model found by state and by store location. As shown, attraction models using "land use" as a categorical factor perform slightly better than the ones using "state." This is an interesting finding because, although the state where a store is located was found to be statistically significant, the best results were found using store location (land use) as the key factor. In essence, this suggests that land use models have a good performance, even when no distinction is made among states.

In addition, results for the comparison of freight trip attraction of grocery stores (see Table 56 and Table 57) have great implications for FTG modeling. They also suggest the transferability of FTG models; the sample, grocery stores exhibit similar FTG patterns across regions. Results also indicate that the models provide good estimates considering the low RMSE found for the sample. As previously shown in Table 57, the LBCS model performs better than the industry-based model. This suggests that implementing a standard land use classification system such as the LBCS could improve FTG modeling. However, past performance is not necessarily a guarantee of future performance, therefore further research is needed. The example discussed in the Seattle Region and Manhattan grocery stores case shows the potential benefits of applying LBCS models for FTG purposes, but it is based on a small sample and should not be generalized.

Table 61. Total estimation error for each classification system (state and store location).

	RMSE	
Classification System	Deliveries Attracted	Pallets Attracted
State	0.392	4.692
Store location	**0.386**	**4.517**

Copyright National Academy of Sciences. All rights reserved.

Use of SIC System and NAICS for FTG Modeling

The SIC system and the NAICS differ in the level of detail that each offers. SIC uses a four-digit code while NAICS employs a six-digit code. The increase in the number of digits from SIC to NAICS allows NAICS to cover a larger number of sectors for a more disaggregated industrial classification system. This characteristic of NAICS provides the advantage of a more detailed system and more flexibility when categorizing subsectors. These differences were evidenced in the estimations of the FTG models for both freight attraction and productions.

Results from the linear regression analysis indicate that some differences in detail between the two classifications systems may reflect different types of models. While all the other industry groupings in the analysis derived from the same model types, the retail industry differed. The freight attraction (receivers) estimation showed that the retail industry estimated a constant FTG per establishment model (Type S) when using SIC, but when using NAICS the estimation resulted in a combined model (Type C). Therefore, retail trade is not dependent on business size when using SIC, but business size is a factor when using NAICS.

Freight production estimation also revealed differences in model types for the retail trade industry. SIC derived a Type C model, consistent with freight attraction results, but NAICS resulted in a FTG rate per employee (Type E) model, which is completely dependent on business size. The results indicate some disparities between SIC and NAICS models as well as differences between freight attraction and production models when using NAICS.

The difference in model types between SIC and NAICS reflects the differences in details at the two-digit level between SIC and NAICS. The dissimilarity for NAICS between freight attraction and production may result from: (1) differences in the number of observations in each sample; or (2) NAICS captures the distinction between freight attraction and production within the retail industry. Regardless of the reasons, the results indicate that disparities exist when using SIC and NAICS in freight transportation modeling.

Multiple Classification Analysis (MCA) was used to estimate trip rates for the industries that were found to be employment dependent (Type E & C models) from the linear regression analyses. The estimated trip rates were used to calculate the RMSE, which serves as the measure of fit of the model, for each two-digit SIC or NAICS code as well as the total RMSE for the entire carriers and receivers samples for both industry classification systems. The models with the best fit using the individual two-digit codes fluctuated between the two systems. However, the overall RMSE values indicated that SIC offered better models for freight trip attraction, and NAICS provided better models for freight trip production.

The findings indicate that the results of FTG estimates are somewhat impacted by the type of industry classification system used in the analysis. The overall results indicate that the replacement of SIC by NAICS codes would lead to more accurate models for freight production models. In the case of freight attraction, SIC is more suitable to capture these freight behaviors. A 3-digit aggregation in NAICS would reduce the internal heterogeneity of the resulting groupings and improve NAICS performance overall, specifically in the area where it is currently lacking, freight attraction. It is important to note that the results shown here are representative of this specific dataset.

Chief Findings for Land Use Based FTG Modeling

As discussed throughout the case chapter, the best models were selected based on t-statistics and RMSE. For 73% of the NYCZR (local) models, a constant coefficient produces the best FTG models; for 18% of these models, FTG depends on employment; and for 9% of these models, the best FTG estimate is a combined model, with a constant coefficient plus an employment term. For 67% of the LBCS Function models, a constant coefficient also produces the best results; for 11% of these Function models, FTG depends on employment; and for 22% of these Function models, FTG is a combined model, with a constant coefficient plus an employment term. For the LBCS Activity models, this breakdown is 80%, 0%, and 20%, respectively. In terms of RMSE, the analysis indicates that NYCZR is somewhat better than LBCS, as the RMSE (4.21) is lower than the one for LBCS (4.53). What is most surprising is that FTG is a constant value in a preponderance of the best performing models, and employment, therefore, plays no role.

For the small number of models where employment is an important factor, MCA was used. The RMSE of the MCA models is 4.43 for NYCZR and 4.60 for LBCS. This indicates that MCA performs slightly better than regression analysis for almost every land use classification where FTG is employment dependent, even though it is a very small difference with respect to the overall error. This is not surprising because MCA has more degrees of freedom than regression analysis, at the expense of higher data requirements.

When the NYCZR and LBCS models are compared to the ITE trip rates, results indicate that NYCZR and LBCS models give more accurate FTG estimates than ITE rates. When considering the complete sample, the total RMSE of NYCZR and LBCS models are about 30% lower than ITE's.

The local and standardized national land use classification code models clearly provide a better alternative to ITE

Copyright National Academy of Sciences. All rights reserved.

trip rates for the following reasons: they give more accurate estimates of freight trip attraction; they cover a wider range of land use classifications; and they are developed exclusively for freight trip attraction. Future research will focus on freight trip production.

The main practical limitation of this research is that the findings are based on a dataset from NYC, specifically Manhattan and Brooklyn. As suggested by the external validity and the transferability findings, the FTG models developed can be extrapolated to similarly situated cities or parts of cities that may have similar freight trip generation patterns. However, the results found are valid only in the context of this dataset.

Comparison Between LBCS, NYCZR, SIC and NAICS

This section discusses the performance of the different FTG models that were estimated. The models were applied to the sample data, and the estimation errors were computed. The RMSE measure was used to identify the most appropriate model for each industry, or group of industries. The analysis was also expanded to identify the best model for each land use category. Detailed tables containing the estimation errors can be found in the supplemental materials and appendices of the Task 11: Case Studies report, available online[10].

The best way to estimate the number of deliveries per establishment is using an industrial classification or land use as the first criteria. According to the category selected, trip generation can depend on business size or not. If it does not depend on business size, the analyst can use a constant number of deliveries per establishment. If it depends on employment, a trip rate table based on MCA can be used.

After identifying the best model for each industry or land use, the next step was to estimate the total error for the pooled data using these individual models to the corresponding observations. As shown in Table 62, SIC models are better than NAICS and land use models, with land use based models giving less accurate results. In addition, the results show the improvements of using individual models; however, the analyst should consider a trade-off between the quality obtained and the efforts to estimate needed inputs for the different models.

Synthetic Correction Validation

Because of data limitations, it is not possible to evaluate how synthetic corrections improve accuracy for every model. However, by using data for grocery stores in the Seattle Region (Section 3.5), it is possible to compare the performance of model BR-1977-1, which is the only model developed for grocery stores, and the corresponding corrected model. Table 63 shows the FTG estimated using the original model, and the corrected model. As shown, the RMSE is 20% lower for the corrected model. Although this is only one example, it is consistent with the theory and shows how the proposed synthetic correction helps to improve the accuracy of the models for FTG estimation.

Table 62. Total estimation error when using the best land use model for each industry or land use.

Classification system	RMSE
SIC	3.332
NAICS	3.566
New York Land Use (NYCZR)	4.205
Land Based Classification System (LBCS)	4.529

The synthetic correction procedure can be applied to any employment trip rate where the dependent variable is in terms of truck trips, and the categorical factor is either an industry segment or a land use compatible with the ones described in the NYC case study. The corrected models were added as new models in the FG/FTG model relational database that was developed.

Summary

Chapter 6 remarks are as follows:

- **Transferability:** Some industry segments such as grocery stores and furniture stores exhibit similar FTG patterns across regions.
- **The use of the SIC system and the NAICS for FTG modeling:** NAICS is best suited to model freight production. On the other hand, SIC better captures freight attraction behaviors.
- **In Most Cases, FTG does not depend on employment, as it is a constant per establishment:** For most of the land uses studied, the best performing models consider FTG as a constant. The same was found for FTG models based on industrial classifications. This finding suggests that as opposed to FG, FTG does not necessarily increase with business size.
- **The land use models estimated with the Land-Based Classification Standards perform better than the corresponding models from the ITE *Trip Generation Manual:*** The models based on land use estimated for this project lead to more accurate FTG estimates than the ITE rates.
- **Use of Multiple Classification Analysis (MCA):** MCA performs slightly better than regression analysis for

[10]Available online at http://transp.rpi.edu/~NCFRP25/downloads.shtml

Copyright National Academy of Sciences. All rights reserved.

Table 63. FTG estimation comparison between original model BR-1977-1 and synthetic correction for grocery wholesale establishments.

Store and Location	Emp.	Observed del/day	FTG-SYN-1995-1* BR-1977-1*	Corrected Version of the model (using Synthetic Correction)
QFC Wallingford	80	19	45	39
QFC Kirkland	70	14	39	34
QFC Mukilteo	70	15	39	34
QFC Capitol Hill	100	14	56	48
QFC Lynnwood	72	13	40	35
Albertsons Kent	60	14	34	29
PCC Issaquah	95	22	53	45
		RMSE	28.73	22.52

**Models can be found in the Database of Task 7 using these codes*

most land use classification, where FTG is employment dependent.

- **FTG models based on industrial classifications (SIC and NAICS) are the most accurate:** Using industrial classification—SIC and NAICS—codes as categorical factors leads to better models than using the land use classifications, e.g., NYCZR and LBCS.
- **Implementing Synthetic Correction increases the performance of FTG models:** This procedure consists of correcting existing employment trip rates to reflect the differences in FTG patterns for small establishments and large establishments. The application of this procedure produced a significant decrease in the estimation errors of FTG models.

Copyright National Academy of Sciences. All rights reserved.

CHAPTER 7

Innovation Plan

This innovation plan introduces a set of comprehensive and practical improvements to FTG modeling practices. There are three interlocking components: the land use and freight systems; the FTG models; and data that planners use or have available to understand the freight impacts of land use decisions.

Future improvements to FTG modeling include the greater use of economic models based on employment. These models can capture the underlying activity of freight, as well as the use of correct spatial aggregation procedures when estimating disaggregate models. Improvements related to data include the use of a standardized data collection instrument which will homogenize the data collection process, and the need to further explore the use of CFS micro-data. More research is needed to quantify service trips generated by commercial establishments, as not much is known about them. In the case of land use based FG/FTG model estimation, the use of LBCS will strengthen the connection between land use definitions and FG/FTG, which will be an improvement on the use of typical land use classification systems that may not capture the underlying economic activity.

Finally, along with the previous improvements, the team encourages the use of the database created as a part of NCFRP Project 25, and provides it as a platform wherein the transportation community can locate information—whether models or literature—on FG/FTG. Users will also be able to improve on the database by editing existing models and adding new ones. The database will also allow for the sharing of data collected with the use of the standardized instrument; this will lead to significant advancements in the area of FG and FTG analysis.

Enhance Freight Trip Generation (FTG) Models Database

The database, created as a part of NCFRP Project 25, houses a comprehensive library of FTG models and publications. This database constitutes a living document, an environment that practitioners and researchers can consult for easy access to the models in the literature, to enhance both practice and research on FG and FTG modeling and analysis. An added recommendation would be to allow the community of practitioners and researchers to enhance the database by identifying gaps in the current models and helping to improve them by editing the existing models or adding new models. However, this would require a moderator to manage the information added to the database for quality assurance.

Conduct Research on Service Trips

Commercial trips are comprised of two types of trips, freight and service. While NCFRP Project 25 focused on freight trips, there is a need for exploration in the area of service trips. Service trips are an increasingly important component of the traffic generated by commercial establishments. Surprisingly, not much is known about how many service trips are produced by commercial establishments in urban areas. These trips are produced by households as well as businesses, freight-related and non-freight-related establishments alike. Currently, these trips are not being accounted for in trip generation models. There needs to be some understanding about these trips, as this knowledge may have significant planning implications. Therefore, more research should be done in the area of service trips to/from commercial establishments so that the findings are in the database. One possibility is to include service trips as a part of FTG models, which is done implicitly when traffic data is used to estimate FTG models.

Use Standardized Instruments for FTG Data Collection

The findings of the literature review performed in Task 3 of NCFRP Project 25 revealed that there is a need for better primary freight data and to remove inconsistencies within

Copyright National Academy of Sciences. All rights reserved.

collected data. Use of a standardized instrument (survey) in the data collection process will address both of these issues, by providing an instrument that will achieve better consistency within the data. The survey design should capture the key aspects of conceptual validity, practicality, and accuracy. Transportation professionals need access to a basic survey design that they can tailor to their specific needs. The uniformity of the data will facilitate data pooling, thus enabling practitioners and researchers to add data to the centralized database. Resulting models from use of this data in FG/FTG analysis may also be uploaded to the database.

The standardized survey instrument along with coding instructions on how to use it will provide more consistent data for model estimation that will allow better comparisons between different cities. Further instructions on how to apply the use of LBCS in FTG analysis will further strengthen the transferability of the models. There also needs to be consistency in vehicle classes and time periods of data collection to achieve comparability of results. Therefore, a standardized instrument should be promoted for use in the data collection process, along with the use of LBCS as the preferred land use classification system in FG/FTG.

Use Commodity Flow Survey (CFS) Micro-Data for Freight Generation (FG) Analysis

The CFS is the most important source of freight demand data in the United States, and one of the oldest data collection programs in transportation. The CFS collects data on the movement of goods in the 50 states and the District of Columbia. It provides information on commodities shipped, their value, weight, and mode of transportation origins and destinations of shipments. The main focus is on shipments sent by domestic establishments in: manufacturing, wholesale, mining, and selected other industries (Fowler 2001; Bureau of Transportation Statistics 2008). As a result, the micro-data file contains about 2.5 million individual records collected for 100,000 establishments.

The CFS data does have some limitations: (1) it only collects data about the outflow of cargo from establishments; and (2) the data collected is for freight generation only, not for FTG. Nevertheless, these limitations can be overcome by developing procedures to estimate the inflow of cargo as a function of the outflow, and also by estimating FTG as a function of the FG.

Accordingly, CFS micro-data should be promoted for use in FG analysis. Further explorations that may be carried out include the use of CFS data to convert FG models to FTG models. The depth of the CFS data provides an opportunity to estimate FTG models at various levels of geographic detail, reflecting regional differences which will assist in the mapping of industry sector models to different land use classifications.

Use Economic Models Based on Industrial Classification Systems

Freight generation (FG) and FTG result from derived demand, they are a result of economic transactions involving cargo. Therefore, it is important to account for the economic activity performed by the establishments—both those that produce and consume freight—as different economic activities may have different FTG patterns. This is typically achieved through the use of industrial classification systems in FTG modeling. The two most important industrial classification systems that are used in FTG modeling are the SIC system and the NAICS. [For more information on these systems see (Pearce, 1957) and (U.S. Census Bureau, 2010c).]

FTG analysis from the case studies showed that the use of industrial classification systems estimated slightly more efficient models than those based on land use classification systems, because land use can only serve as a proxy for the underlying economic activity and industrial classification systems. Results also revealed that for estimating freight production trips, NAICS generated better models than those derived using SIC. In terms of freight attraction, on the other hand, overall SIC produced more efficient models than NAICS, but only marginally so. Therefore, the use of economic models should be based on employment to create FTG models, and in doing so NAICS should be promoted as the preferred classification systems to use in FTG analysis.

Ensure a Better Connection Between Land Use Definitions and FG/FTG

Connections between freight and land use consider two separate aspects: (1) how land use at the establishment level influences FTG; and (2) how freight activity and land use interact with each other at the system level (Holguín-Veras et al. 2011). As mentioned previously, it is necessary to account for the underlying economic activity when generating freight models. In most cases, land use is only a constraint to the production process, not an input factor; therefore, at most, land use is a proxy to the underlying economic activity being conducted by the businesses or more typically, an aggregation of economic sectors. As a result, the adequacy of land use attributes as explanatory variables depends on how well the land use class matches the FTG patterns of the industry segments that have been included under it. In cases where there is a good match, land use variables could be good predictors. In contrast, if the economic/land use class groups use disparate economic activities, independent variables cannot be expected to work well (Holguín-Veras et al. 2011).

Estimation of consistent FTG models based on land use will be valuable to transportation researchers and practitioners and urban planners. Those in charge of zoning regulations

Copyright National Academy of Sciences. All rights reserved.

will particularly benefit from the availability of information related to FTG per land use. FTG estimates based on land use are useful in assessing the FTG effects of planned developments, where the size and footprint are given.

There are various local land use classification systems such as the City of New York Zoning Resolution, which was used in NCFRP Project 25. It categorizes land uses for a specific region. These local land use systems need to be analyzed to assess their capabilities in accounting for freight activity because some land use systems are structured in a way that fully captures freight activity. There is also the question of transferability, how well models generated using a specific local land use classification system are able to be applied to another geographic region. Several studies on FTG have shown that FTG estimates based on land use can produce consistent results.

The LBCS is a national land use system that classifies land use based on the following dimensions: activity, function, structure type, site development character, and ownership, according to the APA (see http://www.planning.org/lbcs/standards). The flexibility of these classification systems enables FTG modeling to account for underlying freight activity and also addresses the issue of transferability of models. The flexibility of the LBCS makes it adaptable for any city, and provides a uniform classification system that will estimate models that may be transferable to other locations.

Therefore, LBCS should be promoted as the lands use classification system that should be employed in FG/FTG analysis.

Use of Appropriate Aggregation Procedures

Spatial aggregation is the process by which estimates at the zonal level are created from a disaggregate model. Although aggregation procedure should be consistent with the mathematical structure of the model at the core of the aggregation, this step is often overlooked. Unlike passenger transportation, where this a minor issue, the variations in FG/FTG patterns require that this issue be addressed on a case-by-case basis.

The aggregation formulas for three key cases are listed below. Though employment is being used in the cases below, the results apply to any other variable as long as the structure is similar (Holguín-Veras et al. 2011).

To understand the following cases, the following formulation is essential. The aggregated FTG, F, is equal to the ***summation of the FTGs for the different establishments***:

$$F = \sum_{i=1}^{n} f_i \tag{8}$$

where

F = Aggregate freight trip generation FTG
E_i = employment at establishment i
f_i = FTG for establishment i

The first case addresses when the *FTG is a function of employment only*. Hence, FTG for the establishment is proportional to employment (FTG rate per employee). The formulation for this is shown in Equation 9, where β is a constant FTG rate per employee.

$$f_i = \beta E_i \tag{9}$$

Substituting Equation 9 in 8 and taking β out of the summation will result in the formulation shown in equation 10 for determining the aggregate FTG (F).

$$F = \sum_{i=1}^{n} \beta E_i = \beta \sum_{i=1}^{n} E_i = \beta E^* \tag{10}$$

Therefore, in cases where the underlying FTG pattern is directly proportional to employment, total FTG is obtained by the ***product of the FTG rate (β) and total employment (E*)***. This estimation process is commonly employed by practitioners in determining zonal estimates of FTG.

The second case formulation addresses the situation when *FTG (f_i) is a constant per establishment*. The mathematical formulation is expressed in Equation 11, where α is a constant.

$$f_i = \alpha \tag{11}$$

Substitution of Equation 11 in Equation 9 and taking α out of the summation results in the formulation shown in Equation 12.

$$F = \sum_{i=1}^{n} \alpha = n\alpha \tag{12}$$

Therefore, in cases where the FTG at the establishment level is constant, the correct estimation process for aggregate FTG is the ***product of the unit FTG (α) and the number of establishments (n)***.

The final case is when ***FTG at the establishment level is determined by a constant and a term that is dependent on employment***. The mathematical formulation is expressed in Equation 13, where α is a constant and β is a constant dependent on employment.

$$f_i = \alpha + \beta E_i \tag{13}$$

Substitution of Equation 13 in to Equation 8 results in the formulation expressed in Equation 14.

$$F = \sum_{i=1}^{n} (\alpha + \beta E_i) = n\alpha + \beta \sum_{i=1}^{n} E_i = n\alpha + \beta E^* \tag{14}$$

Using this method, the total FTG will be obtained from the ***product of the total number of establishments and the constant (α) added to the product of the total employment and the FTG rate (β)***. As can be seen this case is a combination of

Copyright National Academy of Sciences. All rights reserved.

Table 64a. Spatial aggregation procedures for disaggregated models.

Case No.	Model Type	Aggregation Procedures
1	FTG rate per employee	$F=\sum_{i=1}^{n}\beta E_i=\beta\sum_{i=1}^{n}E_i=\beta E^*$
2	FTG constant per establishment	$F=\sum_{i=1}^{n}\alpha=n\alpha$
3	FTG is a combination of a constant and a term that depends on employment level	$F=\sum_{i=1}^{n}(\alpha+\beta E_i)=n\alpha+\beta\sum_{i=1}^{n}E_i=n\alpha+\beta E^*$

F = Aggregate freight trip generation FTG
E_i = Employment at establishment i
E* = Total employment
β = Constant FTG rate per employee
α = Constant
n = Number of establishments

the two previous cases (Holguín-Veras et al. 2011). Table 64a shows the three cases and their correct spatial aggregation procedures.

Therefore, the correct spatial aggregation procedure should be used in FG/FTG analysis.

Use of Synthetic Correction Methodology to Improve Accuracy of Existing Models

The objective of the synthetic correction methodology is to correct existing models to account for the differences in FTG patterns for small establishments and large establishments. In fact, the empirical evidence from the FTG models estimated with establishment-based data indicates that FTG rates depend on business size. In essence, small establishments tend to generate proportionally more trips than large establishments. This leads to a situation in which a constant trip rate underestimates the FTG of small establishments, and overestimates those for large businesses. This poses a problem, because several FTG models reported in the literature are in the form of constant trip rates.

The synthetic correction methodology takes advantage of the mathematical properties of OLS (regression) models and of the case studies developed in Task 11. In essence, this methodology: (1) uses the intercept of the models developed in the case studies to estimate the number of trips produced by small business in the same industry sector; and (2) computes a new slope to account for the effect of employment on large businesses. The key element is that, although an approximation, even a suboptimal assumption of the intercept is bound to perform better than the constant trip rate model.

Copyright National Academy of Sciences. All rights reserved.

CHAPTER 8

Conclusions

This report describes the research findings of project NCFRP Project 25, "Freight Trip Generation and Land Use" (Jointly funded as NCHRP Project 08-80). The main objective was to study the relations between FTG and land use ". . . to develop a handbook that provides improved FTG rates, or equivalent metrics, for different land use characteristics related to freight facilities and commercial operations to better inform state and local decision-making." As part of the research, an in depth examination of the key concepts and modeling methodologies for FTG was conducted. In addition, a set of establishment-level FTG models were estimated for a set of case studies. The research process led to the identification of a number of premises considered to be central to the development of FTG models.

The most important of these premises is the need to make a distinction between FTG, i.e., the generation of vehicle trips, and FG, i.e., the generation of the cargo that is transported by the vehicle trips. Furthermore, FTG is the result of the logistic decisions concerning how best to transport the FG in terms of shipment size, frequency of deliveries, and the vehicle/mode used. In some cases, this allows carrier companies to increase the cargo transported (the FG) without proportionally increasing the corresponding FTG. As a result, FTG cannot be universally assumed to be proportional to business size because large establishments could receive larger amounts of cargo without concomitant increases in FTG. This calls into question standard practices that assume proportionality between FTG and business size variables.

Another important premise is that the accuracy of FG/FTG analyses depends on a number of key factors: (1) the adequacy of the classification system used to group commercial establishments in a set of standardized classes; (2) the ability of the measure of business size used to capture the intensity of FG/FTG; (3) the validity of the statistical technique used to estimate the model; and, (4) the correctness of the aggregation procedure used to estimate aggregate values.

In terms of land use, the research reviewed different definitions and found a variety of non-integrated applications and classification codes currently in use. These can be categorized into three groups: the ones using structure type or site descriptor (e.g., ITE Manual or Tax Assessor's codes); those using industry sectors at the establishment level (e.g., SIC or NAICS); and those using land use planning designations (e.g., LBCS and NYCZR). However, there is no one single land use classification system appropriate for freight. Moreover, the analyses revealed a number of aspects of great relevance for modeling purposes: it is important to use land use classification systems that lead to internally homogeneous classes, in terms of the determinants and patterns of FG/FTG activity, and it is important to use, as predictors of FG/FTG, variables that correctly measure the intensity of FG/FTG activity.

The premises and conjectures discussed herein were tested using cases studies. To this effect, the research used FG/FTG data from: receiver companies in Manhattan and Brooklyn; carrier companies in Northern New Jersey and New York; a furniture store chain in Midwestern States; and, supermarkets in the Puget Sound region and Manhattan. Using the data, the research compared the performance of FG/FTG models based on: (1) Industrial classification systems (i.e., SIC, and NAICS); (2) Land use classification systems (i.e., LBCS and NYCZR); (3) the statistical technique used (e.g., OLS, multiple classification analyses); (4) the aggregation procedure used; and (5) the business size variable used as predictors of FG/FTG. The case studies confirmed the superiority of economic classification systems over standard land use classification systems; revealed that using economic classification systems as the foundation for the estimation of FG/FTG models is significantly better than using standard land use classification systems such as the NYCZR, or land use classification systems that can be applied nationally such as LBCS; indicated that MCA performed better than OLS models; and confirmed that proportionality between FTG and business size only happens in a minority of industry segments. It also

Copyright National Academy of Sciences. All rights reserved.

revealed that in 51% of industry segments the FTG is constant as it does not depend on business size; in 31% of cases the FTG model is a function of a constant and a rate that multiplies the establishment's employment; and in the remainder 18% of cases the FTG model is proportional to employment and a constant FTG rate. In addition, the case studies suggest that the models estimated at the establishment level are transferable, though more testing is needed to reach solid conclusions, and that the NCFRP Project 25 models outperform both the ITE, and some industry segments of the Quick Freight Response Manual (QFRM).

Although the work completed has primarily focused on FTG, the findings just discussed have important significant implications for both freight transportation planning and traffic impact analyses. During the second phase of the NCFRP 25—which will use the CFS—the research will focus on the estimation of FG models. Ultimately, the entire set of findings will be synthesized in a set of guidelines for FG/FTG modeling.

Copyright National Academy of Sciences. All rights reserved.

References

Abdelwahab, W. M. and M. A. Sargious (1991). "A Simultaneous Decision-Making Approach to Model the Demand for Freight Transportation." *Canadian Journal of Civil Engineering* **18**(3): 515–520.

Al-Battaineh, O. and I. Kaysi (2005). Commodity-Based Truck Origin-Destination Matrix Estimation Using Input-Output Data and Genetic Algorithms. in *Transportation Research Record: Journal of the Transportation Research Board* **1923**(-1): 37–45. Transportation Research Board of the National Academies, Washington, D.C.

Al-Deek, H. M. (2001). "Comparison Between Neural Networks and Multiple Regression Approaches for Developing Freight Planning Models with Specific Applications to Seaports." 80th Annual Meeting of the Transportation Research Board, Washington, D.C.

Al-Deek, H. M., G. Johnson, A. Mohamed and A. El-Maghraby (2000). "Truck Trip Generation Models for Seaports with Container-Trailer Operations." 79th Annual Meeting of the Transportation Research Board, Washington, D.C., National Academy Press.

Amari, L. F., V. Marusic and K. Amari (no date). "A Land Use and Land Cover Classification System for Use with Remote Sensor Data." Posted: Retrieved April 6, 2010, from www.usbr.gov/lc/socal/reports/SMappend_C.pdf.

American Planning Association (1994). "Toward a Standardized Land-Use Coding Standard." Posted: Retrieved March 15, 2010, from www.planning.org/lbcs/background/scopingpaper.htm.

Bartholomew, H. (1955). *Land Uses in American Cities,* Cambridge: Harvard University Press.

Bartlett, R. S. and W. H. Newton (1982). Goods Vehicle Trip Generation and Attraction by Industrial and Commercial Premises. Transport and Road Research Laboratory. 1059.

Bastida, C. and J. Holguín-Veras (2009). "Freight Generation Models." *Transportation Research Record: Journal of the Transportation Research Board* 2097(-1): 51–61.

Baumol, W. J. and H. D. Vinoud (1970). "An Inventory Theoretic Model of Freight Transport Demand." *Management Science* **16**(7): 413–421.

Beagan, D., M. Fischer and A. Kuppam (2007). Quick Response Freight Manual II. Department of Transportation. Federal Highway Administration. FHWA-HOP-08-010 EDL No. 14396.

Berke, P., D. R. Godschalk, E. J. Kaiser and D. Rodriguez (2006). *Urban Land Use Planning 5th ed.* Chicago, IL, University of Illinois Press.

Blaesser, B. and A. Weinstein (1989). *Land Use and the Constitution: Principles for Planning Practice.* Chicago, IL., Planners Press.

Boyce, D. (2002). Combined Model of Interregional Commodity Flows on a Transportation Network. *Trade, Networks and Hierarchies.* G. J. D. Hewings, M. Sonis and D. Boyce, Springer.

Bröcker, J. (1998). "Operational spatial computable general equilibrium models." *Annals of Regional Science 32:* 367–387.

Brogan, J. D. (1980). Improving Truck Trip-Generation Techniques through Trip-End Stratification. In *Transportation Research Record* 771: 1–6. TRB, National Research Council, Washington, D.C.

Bureau of Economic Analysis (2007). "Regional Multipliers from the Regional Input-Output Modeling System (RIMS II): A Brief Description." Posted: Retrieved July 06, 2007 from http://www.bea.gov/bea/regional/rims/brfdesc.cfm#f4.

Bureau of Local Assessment (2009). "Property Type Classification Codes, Non-arms Length Codes and Sales Report Spreadsheet Specifications." Division of Local Services, Massachusetts Department of Revenue. Posted: from www.mass.gov/Ador/docs/dls/bla/classificationcodebook.pdf.

Bureau of Transportation Statistics (1996). 1996 Directory of Transportation Data Sources. Bureau of Transportation Statistics.

Bureau of Transportation Statistics (2008). Commodity Flow Survey: Detailed Description 2007 http://www.bts.gov/programs/commodity_flow_survey/detailed_description/index.html.

Bureau of Transportation Statistics (2009). Commodity Flow Survey: Reported mode volumes. 2007 http://www.bts.gov/help/commodity_flow_survey.html#reported_mode_transportation.

Cambridge Systematics (1996). Travel Survey Manual. Department of Transportation.

Cambridge Systematics Inc. (1996). *Quick Response Freight Manual.* Final Report of the Federal Highway Administration. Cambridge Systematics, Inc.

Cambridge Systematics Inc. (2010a). Draft Transportation 2040 Regional Freight Strategy, Towards a Sustainable Transportation System. Puget Sound Regional Council. http://www.psrc.org/assets/3616/T2040_freight_strategy_full_w_cover_030310draft.pdf.

Cambridge Systematics Inc. (2010b). "Regional Freight System Planning Recommendations, Regional Framework & Policy Recommendations, Draft Tech Memo prepared for the Chicago Metropolitan Agency for Planning (CMAP)."

Chapin, S. (1957). *Urban Land Use Planning,* New York: Harper and Brothers.

City of Boston [Massachusetts] Redevelopment Authority (1990 as amended through 2006). Zoning Code: Article 42D "Waterfront Manufacturing District."

City of Portland [Oregon] Bureau of Planning and Sustainability (2010). "Comprehensive Plan—zoning code." Posted: from http://www.portlandonline.com/bps/index.cfm?a=64435&c=36238.

Copyright National Academy of Sciences. All rights reserved.

City of Portland [Oregon] Office of Transportation (2006). "Exhibit A: City of Portland Freight Master Plan." Posted: from http://www.portlandonline.com/shared/cfm/image.cfm?id=112552.

de la Barra, T. (1989). *Integrated Land Use and Transport Modeling,* Cambridge Urban and Architectural Studies.

DeVries, J. B. and S. V. Dermisi (2008). Regional Warehouse trip production analysis: Chicago Metro Analysis. Illinois Center for Transportation.

Duerksen, C. (2008). "Saving the World Through Zoning." *Planning* 74(1): 28–33.

Federal Highway Agency (1999). *Guidebook on Statewide Travel Forecasting.* University of Wisconsin-Milwaukee and the Wisconsin Department of Transportation. Center for Urban Transportation Studies.

Fisher, G. (1996). *The Worst Tax? A History of the Property Tax in America.* Lawrence, Kansas, University Press of Kansas.

Fisher, Michael J. and Myong Han (2001). *NCHRP Synthesis 298: Truck Trip Generation Data.* Transportation Research Board. Transportation Research Board of the National Academies, Washington, D.C.

Fowler, J. (2001). The Commodity Flow Survey and Hazardous Materials Safety Data: Perspectives on Use, Content, and Needs for the Future. 80th Annual Meeting of the Transportation Research Board, Washington.

Freilich, R. (1999). *From Sprawl to Smart Growth: Successful Legal, Planning, and Environmental Systems.* Chicago, Illinois, ABA Publishing.

Garrido, R. A. (2000). "Spatial interaction between trucks flows through the Mexico-Texas border." Transportation Research. A **33**(1): 23–33.

Giuliano, G., P. Gordon, Q. Pan, J. Park and L. Wang (2007). "Estimating Freight Flows for Metropolitan Area Highway Networks Using Secondary Data Sources." *Networks and Spatial Economics* **10**(1): 73–91. 10.1007/s11067-007-9024-9.

Greene, W. H. (1993). *Econometric Analysis,* Prentice-Hall.

Guha, T. and C. M. Walton (1993). "Intermodal Container Ports: Application of Automatic Vehicle Classification System for Collecting Trip Generation Data." Transportation Research Record 1383: 17–23. TRB, National Research Council, Washington, D.C.

Guttenberg, A. Z. (1993). *The Language of Planning: Essays on the Origins and Ends of American Planning Thought.* Urbana, Il. University of Illinois Press.

Hall, R. (1985). "Dependence between Shipment Size and Mode in Freight Transportation." *Transportation Science* 19(4): 436–444.

Harris, F. (1915). *Operations and Costs.* Chicago, IL, A. W. Shaw.

Hausrath Economics Group and Cambridge Systematics Inc. (2004). MTC Goods Movement Study Phase 2: Task 11 Working Paper: A Land Use Strategy to Support Regional Goods Movement in the Bay Area. Metropolitan Transportation Commission (MTC). http://www.mtc.ca.gov/planning/rgm/Task11.pdf.

Hewings, G., M. Sonis and D. Boyce (2002). Trade, Networks, and Hierarchies: Modeling Regional and Interregional Economies. Berlin, Germany, Springer.

Holguín-Veras, J. (2002). "Revealed Preference Analysis of the Commercial Vehicle Choice Process." Journal of Transportation Engineering, American Society of Civil Engineers 128(4): 336–346.

Holguín-Veras, J. (2006). Potential for Off-Peak Freight Deliveries to Congested Urban Areas Rensselaer Polytechnic Institute. http://www.rpi.edu/~holguj2/OPD/OPD_FINAL_REPORT_12-18-06.pdf.

Holguín-Veras, J., M. Jaller and L. Destro (2010). Feasibility Study for Freight Data Collection—Final Report http://www.utrc2.org/research/assets/190/NYMTC-Freight-Data-Final-rpt1.pdf.

Holguín-Veras, J., M. Jaller, L. Destro, X. Ban, C. Lawson and H. Levinson (2011). "Freight Generation, Freight Trip Generation, and the Perils of Using Constant Trip Rates." *Transportation Research Record* **(in print)**.

Holguín-Veras, J., G. List, A. Meyburg, K. Ozbay, R. Paaswell, H. Teng and S. Yahalom (2001). "An Assessment of Methodological Alternatives for a Regional Freight Model in the NYMTC Region."

Holguín-Veras, J., Y. López-Genao and A. Salam (2002). "Truck-Trip Generation at Container Terminals." Transportation Research Record: Journal of the Transportation Research Board 1790: 89–96. Transportation Research Board of the National Academies, Washington, D.C.

Holguín-Veras, J., K. Ozbay and A. D. Cerreño (2005). Evaluation Study of the Port Authority of New York and New Jersey's Time of Day Pricing Initiative. http://www.rpi.edu/~holguj2/PA/index.html.

Holguín-Veras, J. and G. Patil (2005). "Observed Trip Chain Behavior of Commercial Vehicles." *Transportation Research Record* 1906: 74–80.

Holguín-Veras, J. and E. Thorson (2000). "An Investigation of the Relationships between the Trip Length Distributions in Commodity-based and Trip-based Freight Demand Modeling." Transportation Research Record: Journal of the Transportation Research Board 1707: 37–48. Transportation Research Board of the National Academies, Washington, D.C.

Holguín-Veras, J. and E. Thorson (2003a). "Modeling Commercial Vehicle Empty Trips with a First Order Trip Chain Model." *Transportation Research Part B: Methodological* 37(2): 129–148.

Holguín-Veras, J. and E. Thorson (2003b). "Practical implications of Modeling Commercial Vehicle Empty Trips." *Transportation Research Record: Journal of the Transportation Research Board* **1833:** 87–94.

Holguín-Veras, J., Q. Wang, N. Xu, K. Ozbay, M. Cetin and J. Polimeni (2006). "Impacts of Time of Day Pricing on the Behavior of Freight Carriers in a Congested Urban Area: Implications to Road Pricing." *Transportation Research Part A: Policy and Practice* 40 (9): 744–766.

Holguín-Veras, J., N. Xu, G. d. Jong and H. Maurer (2009). "An Experimental Economics Investigation of Shipper-Carrier Interactions on the Choice of Mode and Shipment Size in Freight Transport." *Networks and Spatial Economics.* 10.1007/s11067-009-9107-x.

Iding, M. H. E., W. J. Meester and L. A. Tavasszy (2002). Freight trip generation by firms. *42nd European Congress of the European Regional Science Association.* Dortmund, Germany.

Institute of Transportation Engineers (2004). *Trip Generation Handbook: An ITE Recommended Practice.* Washington, D.C.

Institute of Transportation Engineers (2008). T*rip Generation: An ITE Informational Report.* Washington, D.C., Institute of Transportation Engineers.

Ivanova, O., A. Vold and V. Jean-Hansen (2002). PINGO a Model for Prediction of Regional and Interregional freight transport. Institute of Transport Economics. TØI report 578/2002.

Jack Faucett Associates (1999). Research and Development of Destination, Mode, and Routing Choice Models for Freight. Jack Faucett Associates.

Jeer, S. (1997). LBCS Discussion Issues. American Planning Association.

Jensen, J. (2007). Remote Sensing of the Environment: An Earth Resource Perspective. Upper Saddle River, NJ, Pearson, Prentice Press.

Jessup, E., K. L. Casavant and C. T. Lawson (2004). Truck Trip Data Collection Methods. Oregon Department of Transportation. Federal Highway Administration. SPR 343 http://www.oregon.gov/ODOT/TD/TP_RES/docs/Reports/TruckTripData.pdf.

Jong, G., H. Gunn and W. Walker (2004). "National and International Freight Transport Models: Overview and Ideas for Future Development." Transport Reviews 23(1).

Journal of Commerce (2011). "NYK Offers Free Tsunami Aid Transport." *The Journal of Commerce*. Issue: March 22, 2011, Retrieved from http://www.joc.com/maritime/nyk-offers-free-tsunami-aid-transport.

Kanafani, A. (1983). Transportation Demand Analysis, McGraw Hill.

Copyright National Academy of Sciences. All rights reserved.

Kawamura, K., H.-S. Shin and S. McNeil (2005). Business and Site Specific Trip Generation Methodology For Truck Trips, Midwest Regional University Transportation Center at University of Wisconsin, Madison.

Mandelker, D., J. Payne, J. P. Salsich and N. Stroud (2008). Planning and Control of Land Development: Case and Materials. Newark, NJ.

Marker, J. T. J. and K. G. Goulis (1998). Truck Traffic Prediction Using the Quick Response Freight Model Under Different Degrees of Geographic Resolution: A GIS Application in Pennsylvania. 77th Annual Meeting of Transportation Research Board. Washington, D.C.

McCormack, E. and A. Bassok (2011). "Evaluating Two Low-Cost Methods of Collecting Truck Generation Data Using Grocery Stores." *ITE Journal* 81(6): 34–38.

McFadden, D., C. Winston and A. Boersch-Supan (1986). Joint Estimation of Freight Transportation Decisions under Non-Random Sampling. Analytical Studies in Transport Economics. A. Daugherty, Cambridge University Press: 137–157.

Metropolitan Planning Commission of Nashville and Davidson County. (2006). "Detailed Neighborhood Design Plan for Cleveland Park, McFerrin Park, and Greenwood Neighborhoods." Appendix: Charrette Process 38. Posted: from http://www.nashville.gov/mpc/subarea/subarea5.asp.

Metropolitan Transportation Commission (2009). Goods Movement Initiatives 2009 Update http://www.mtc.ca.gov/planning/2035_plan/Supplementary/T2035_Goods_movement_update.pdf.

Middleton, D. R., J. M. Mason Jr and T. Chira-Chavala (1986). Trip Generation for Special-Use Truck Traffic. In *Transportation Research Record 1090:* 8–13. TRB, National Research Council, Washington, D.C.

Miller, K. S., T. N. Harvey, P. W. Shuldiner and C. W. Ho (1993). "Using Video Technology to Conduct 1991 Boston Region External Cordon Survey." *Transportation Research Record 1412:* 46–56. TRB, National Research Council, Washington, D.C.

Mitchell, R. and C. Rapkin (1954). *Urban Traffic: A Function of Land Use.* New York, Columbia University Press.

NAICS Association (n.d.). NAICS Information: The History of NAICS and More.

National Capital Region Transportation Planning Board (2010). "Transportation/Land Use Connections Program." Posted: Retrieved April 10, 2010, from http://www.mwcog.org/transportation/activities/tlc/clearinghouse/strategies/integrate.asp.

National Cooperative Highway Research Program (2008a). Forecasting Metropolitan Commercial and Freight Travel. Transportation Research Board. NCHRP Synthesis **384**.

National Cooperative Highway Research Program (2008b). Forecasting Statewide Freight Toolkit. Transportation Research Board. NCHRP Report **606**.

New York Constitution of 1938 (1938). "art. XVI, § 2." Posted: from http://www.dos.state.ny.us/info/constitution.htm.

New York State Office of Real Property Services (2006). "Assesor's Manual." Posted: 6, from http://www.orps.state.ny.us/assessor/manuals/vol6/ref/prclas.htm.

Nolon, J., P. Salkin and M. Gitelman (2008). *Cases and Materials on Land Use and Community Development*. St. Paul, MN., Thomson/West.

Novak, D., C. Hodgdon, F. Guo and L. Aultman-Hall (2008). "Nationwide Freight Generation Models: A Spatial Regression Approach." *Networks and Spatial Economics*.

NYC Department of City Planning (2010). "Zoning Districts." Posted: Retrieved 07/07/2011, from http://www.nyc.gov/html/dcp/html/zone/zonetext.shtml.

Ogden, K. W. (1992). *Urban Goods Movement*. London, England, Ashgate Publishing.

Oosterhaven, J., T. Knaap, C. J. Ruijgrok. and L. A. Tavasszy (2001). *On the development of RAEM: the Dutch spatial general equilibrium model and its first application*. 41st European Regional Science Association Conference, Zagreb.

Orsini, D., O. Gavaud and P. L. Bourhis (2009). *Logistics Facilities Impacts on the Territory*. 2009 European Transport Conference, London: AET.

Ortúzar, J. D. and L. G. Willumsen (2001). *Modelling Transport*. New York, John Wiley and Sons.

Patier, D. and J. Routhier (2008). *How to improve the capture of urban goods movement data?* 8th international conference on survey methods in transport, Annecy, France.

Pearce, E. (1957). History of the Standard Industrial Classification. Prepared for the Executive Office of the President, Bureau of the Budget.

Rizet, C., M. Guilbault, J. v. Meijeren, E. Bijster and M. Houée (2003). Tracking Along the Transport Chain Via the Shipper Survey. *Transport Survey Quality and Innovation*. P. Stopher and P. Jones. Oxford, Pergamon: 427–442.

Rodrigue, J.-P., C. Comtois and B. Slack (2006). The Geography of Transport Systems, Hofstra University, Department of Economics and Geography.

Routhier, J.-L., E. Segalou and S. Durand (2002). Mesurer l'impact du transport de marchandises en ville: le modèle de simulation FRETURB v1. Marchandises en ville

Russo, F. and A. Comi (2002). Urban Freight Movement: a quantity attraction model. Urban Transport VIII: Urban Transport and the Environment in the 21st Century W. Press.

Samuelson, R. D. (1977). Modeling the Freight Rate Structure. Center for Transportation Studies, Massachusetts Institute of Technology.

Sharma, S., G. X. Liu and S. Thomas (1998). "Sources of Error in Estimating Truck Traffic from Automatic Vehicle Classification Data." *Journal of Transportation and Statistics* **1**(3).

Simchi-Levi, D., X. Chen and J. Bramel (2005). *The Logic of Logistics*, Springer.

Sorratini, J. and R. Smith (2000). "Development of a Statewide Truck Trip Forecasting Model Based on Commodity Flows and Input-Output Coefficients." *Transportation Research Record: Journal of the Transportation Research Board* **1707**(-1): 49–55.

Sorratini, J. A. (2000). "Estimation Statewide Truck Trips Using Commodity Flows and Input-Output Coefficients." *Journal of Transportation and Statistics* **3**(1): 53–67.

Sparks, R. (1958). "The Case for a Uniform Land Use Classification." *Journal of the American Institute of Planners* **24**(3): 174–178.

Strauss-Wieder, A., K. Kang and M. Yokei (1989). *The Truck Commodity Survey in the New York-New Jersey Metropolitan Area*. Good Transportation in Urban Areas, Proceedings of the 5th Conference, Santa Barbara, CA.

Swahn, H. (2001). The Swedish National Model system for Goods Transport. SIKA.

Ta, C., E. McCormack and A. Bassok (2010). Truck Trip Generation by Grocery Stores. **Agreement T4118, Task 01.** W.S.T.C. (TRAC).

Tadi, R. R. and P. Balbach (1994). "Truck Trip Generation Characteristics of Nonresidential Land Uses." *ITE Journal* **64**(7): 43–47.

Taniguchi, E. and R. G. Thompson (2002). "Modeling city logistics." *Transportation Research Record* **1790**: 45–51.

Tavasszy, L. A., M. van de Vlist, C. Ruijgrok and J. van de Rest (1998). *Scenario-wise analysis of transport and logistic systems with a SMILE*. WCTR Conference, Antwerp.

The Tioga Group, Economic & Planning Systems, Meyer, Mohaddes Associates and J. O'Connell (2006). SACOG Regional Goods Movement Study: Phase One Report. the Sacramento Area Council of Governments.

Copyright National Academy of Sciences. All rights reserved.

U.S. Census Bureau (2004a). "American Community Survey: 2003 Data Profile." Posted: Retrieved July 22, 2007, from http://www.census.gov/acs/www/Products/Profiles/Single/2003/ACS/Tabular/060/06000US36085709153.htm.

U.S. Census Bureau (2004b). Vehicle Inventory and Use Survey. http://www.census.gov/prod/ec02/ec02tv-us.pdf.

U.S. Census Bureau (2010a). "Commodity Flow Survey." Posted, April 2, 2010, from http://www.census.gov/econ/www/se0700.html.

U.S. Census Bureau (2010b). "County Business Patterns." Posted, April 2, 2010, from http://www.census.gov/econ/www/se0700.html.

U.S. Census Bureau (2010c). "North American Industry Classification System." Posted: from http://www.census.gov/eos/www/naics.

U.S. Census Bureau (2011). "Zip Code Business Patterns." Posted: Retrieved July 25, 2011, from http://www.census.gov/epcd/www/zbp_base.html.

U.S. Department of Transportation (1996). Quick Response Freight Manual. Federal Highway Administration. **DTFH61-93-C-00075 and DTFH61-93-C-00216.**

Urban Renewal Administration Housing and Home Finance Agency and Bureau of Public Roads (1965). *Standard Land Use Coding Manual: A Standard System for Identifying and Coding Land Use Activities*. Washington, D.C., Department of Commerce.

Wagner, T. (2010). "Regional traffic impacts of logistics-related land use." *Transport Policy*. 10.1016/j.tranpol.2010.01.012.

Waliszewski, J., D. Ahanotu and M. Fischer (2004). "Comparison of Commodity Flow Forecasting Techniques in Montana." *Transportation Research Record: Journal of the Transportation Research Board* **1870**(-1): 1–9.

Wallis, J. (2001). *A History of the Property Tax in America in Oates, W. ed.* Cambridge, MA., Lincoln Institute of Land Policy.

Wegmann, F. J., A. Chatterjee, M. E. Lipinski, B. E. Jennings and R. E. McGinnis (1995). Characteristics of Urban Freight Systems. FHWA. **DOT-T-96-22.**

Weisbrod, R., E. Swiger, G. Muller, M. Rugg and M. K. Murphy (2002). Global Freight Villages: A Solution to the Urban Freight Dilemma. *TRB Annual Meeting*. Washington, D.C.

WSP Policy & Research (2005). The EUNET 2.0 Freight and Logistics Model—Final report, regional pilot for economic/logistic methods. UK Department for Transport. **DfT contract ppad 9/134/24.**

Zavattero, D. A. and S. E. Weseman (1981). "Commercial Vehicle Trip Generation in Chicago Region." *Transportation Research Board* **R34**: 12–15.

Zettle, R. and R. Caril (1962). *Summary Review of Major Metropolitan Area Transportation Studies in the United States*. Berkeley.

Zhao, Y. and K. M. Kockelman (2004). "The random-utility-based multiregional input-output model: solution existence and uniqueness." *Transportation Research Part B: Methodological* **38**(9): 789–807.

Copyright National Academy of Sciences. All rights reserved.

APPENDIX A

ITE Trip Generation Manual

A manual developed by the Institute of Transportation Engineers (ITE), Trip Generation, 8th Edition, provides information for estimating the number of vehicle trips that may be generated by a specific building category, under a land use category. The information in this manual is provided based on approximately 4,800 trip generation studies submitted to ITE by: public agencies, consulting firms, universities and colleges, developers, associations, and local sections, districts and student chapters of ITE (Institute of Transportation Engineers 2008). The ITE Manual contains trip rates data for 162 land uses, under ten major land use categories for several time analysis periods (e.g., weekdays and weekends). These major land use categories are: Port and Terminal (Land Uses 000-099), Industrial/Agricultural (Land Uses 100-199); Residential (Land Uses 200–299); Lodging (Land Uses 300–399); Recreational (Land Uses 400–499); Institutional (Land Uses 500–599); Medical (Land Uses 600–699); Office (Land Uses 700–799); Retail (Land Uses 800–899), and Services (Land Uses 900–999). The land use classes directly related to freight activity are listed in Table 64b.

The land use classes in Table 64b are those that have explicitly calculated FTG rates, based on a percentage of total traffic. The classification type is a single code, and the geography is a single "site," though it is unclear if the site is a tax parcel or a structure.

Table 64b. ITE land use classes related to freight.

Land Use Code	Land Use Category
010	Waterport/Marine Terminal
021	Commercial Airport
022	General Aviation Airport
30	Truck Terminal
130	Industrial Park
150	Warehousing
151	Mini-Warehouse
152	High-Cube Warehouse
254	Assisted Living
731	State Motor Vehicles Department
732	United States Post Office
760	Research and Development Center
813	Free-Standing Discount Superstore
815	Free-Standing Discount Store
816	Hardware/Paint Store
860	Wholesale Market
890	Furniture Store
931	Quality Restaurant

Copyright National Academy of Sciences. All rights reserved.

APPENDIX B

Number of Vendors vs. Business Size

This Appendix shows the data concerning number of vendors vs. business size for a sample of establishments in NYC in the food, wholesale trade, and retail trade sectors.

Retail Trade

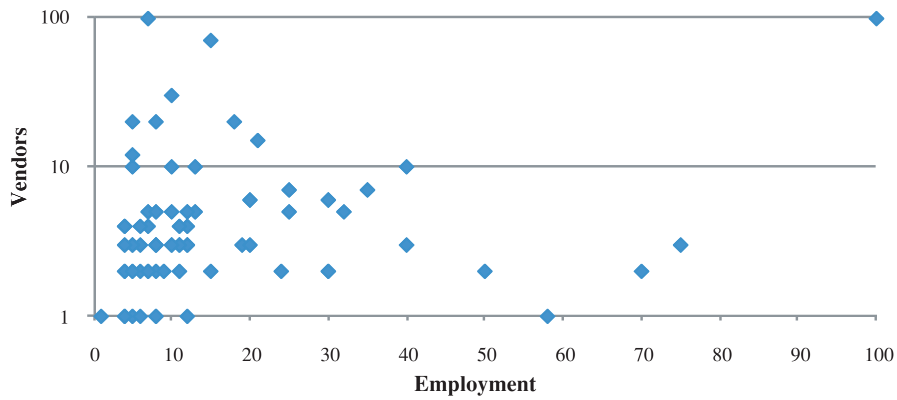


Figure 13. Number of vendors vs. number of employees: retail trade industry.

SUMMARY OUTPUT

Regression Statistics	
Multiple R	0.032513872
R Square	0.001057152
Adjusted R Square	-0.007130904
Standard Error	248.6312227
Observations	124

ANOVA

	df	*SS*	*MS*	*F*	*Significance F*
Regression	1	7981.194665	7981.1947	0.129109	0.719978792
Residual	122	7541733.16	61817.485		
Total	123	7549714.355			

	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*
Intercept	-62.71341	23.85713014	-2.628707	0.0096731	-109.94098	-15.48584
X Variable 1	0.1214605	0.33803182	0.3593174	0.7199788	-0.54770598	0.790627

As shown, the coefficient for the number of employees as an independent variable is not statistically significant; in contrast, the intercept is significant at the 90% confidence level. As a result, the number of vendors that deliver products to these establishments is statistically constant.

Copyright National Academy of Sciences. All rights reserved.

Wholesale Trade

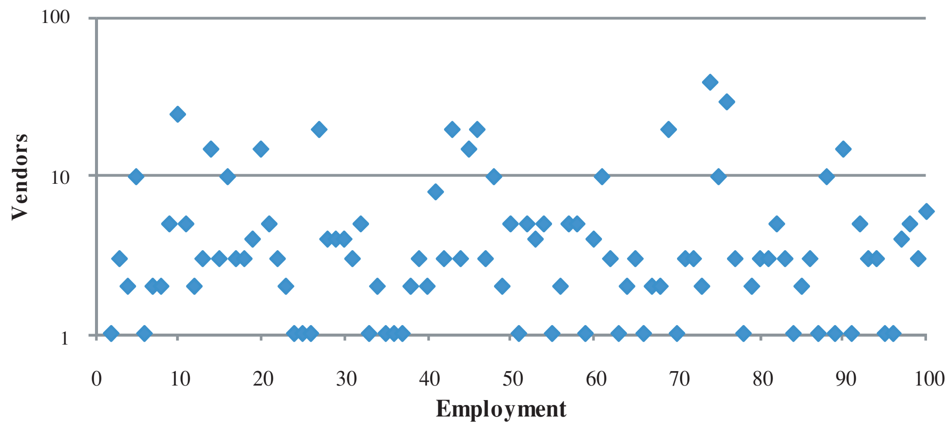


Figure 14. Number of vendors vs. number of employees: wholesale trade industry.

SUMMARY OUTPUT

Regression Statistics	
Multiple R	0.032513872
R Square	0.001057152
Adjusted R Square	-0.007130904
Standard Error	248.6312227
Observations	124

ANOVA

	df	*SS*	*MS*	*F*	*Significance F*
Regression	1	7981.194665	7981.1947	0.129109	0.719978792
Residual	122	7541733.16	61817.485		
Total	123	7549714.355			

	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*
Intercept	-62.71341	23.85713014	-2.628707	0.0096731	-109.94098	-15.48584
X Variable 1	0.1214605	0.33803182	0.3593174	0.7199788	-0.54770598	0.790627

As shown, the coefficient for the number of employees as an independent variable is not statistically significant; in contrast, the intercept is significant at the 99% confidence level. As a result, the number of vendors that deliver products to these establishments is statistically constant.

Copyright National Academy of Sciences. All rights reserved.

Food

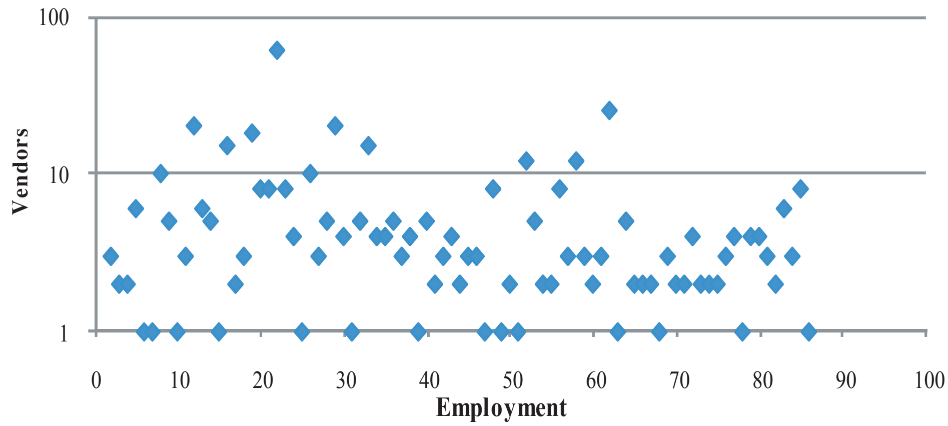


Figure 15. Number of vendors vs. number of employees: food industry.

SUMMARY OUTPUT

Regression Statistics	
Multiple R	0.060961414
R Square	0.003716294
Adjusted R Square	-0.00773524
Standard Error	150.4642036
Observations	89

ANOVA

	df	*SS*	*MS*	*F*	*Significance F*
Regression	1	7347.044418	7347.0444	0.3245236	0.570369777
Residual	87	1969634.461	22639.477		
Total	88	1976981.506			

	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower95%*	*Upper95%*
Intercept	-22.7595	18.67544437	-1.218686	0.2262578	-59.8789632	14.359971
X Variable 1	0.1751761	0.30750464	0.5696697	0.5703698	-0.43602267	0.7863748

As shown, the coefficient for the number of employees as an independent variable is not statistically significant; in contrast, the intercept is significant at the 80% confidence level. As a result, the number of vendors that deliver products to these establishments is statistically constant.

Copyright National Academy of Sciences. All rights reserved.

APPENDIX C

Number of Deliveries vs. Business Size

This Appendix shows the results for SIC 50 Wholesale Trade: Durable Goods. As shown in Table 65, the number of deliveries per employee for small businesses is about six times the number of deliveries for large businesses.

Table 65. Breakdown of results obtained for NYC.

Employment Range	Total Employees	Deliveries per day	Del/Empl	Number of Establishments
5<	12	5	0.42	4
5-9	107	26	0.24	16
10-19	237	52.4	0.22	17
20-49	289	51.2	0.18	11
50-99	255	18	0.07	5

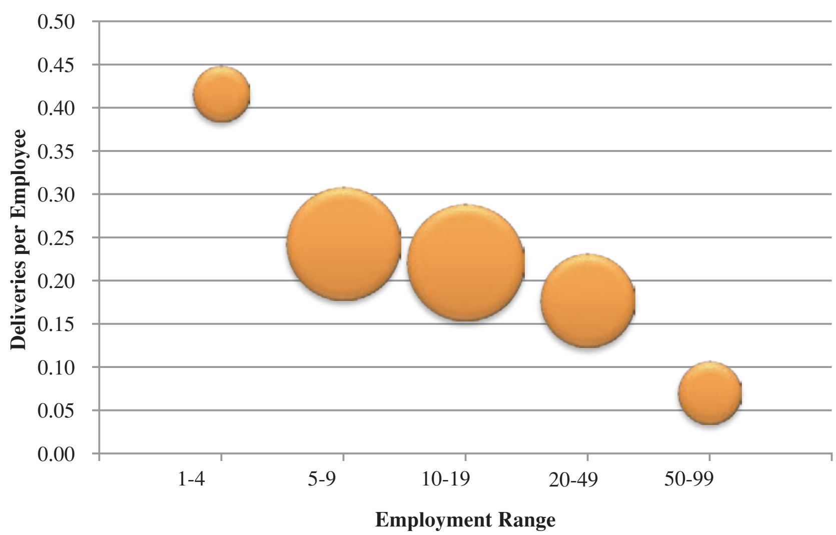


Figure 16. Deliveries per employee vs. employment: SIC 50: Wholesale Trade.

Copyright National Academy of Sciences. All rights reserved.

APPENDIX D

Review of the Literature on Freight Trip Generation Modeling

This chapter summarizes the current literature on FG and FTG modeling. It provides a comprehensive review of the state-of-the-art research and practice in FTG, with critical examination of the technical merits, advantages, and disadvantages of different FTG methods and models.

Freight Trip Generation (FTG) Modeling

This section reviews the state-of-the-art research and practice in FTG analysis and modeling. It includes both domestic and international FTG modeling efforts. The FTG models are reviewed in terms of factors that serve to classify a specific FTG model. The various factors that should be considered in developing and analyzing freight modeling techniques are given in Table 66. They include: dependent and independent variables, levels of aggregation and geography, estimation techniques, and model structure. Table 67 provides a summary of various FTG models that are reviewed in this document. To facilitate interpretation and analysis, Table 68 shows the breakdown of the features of the models by level of geography. As shown, the majority of the models are for states (35%), and metropolitan areas (39%). Corridor and facility specific applications represent the remaining 26%.

Table 66. Review factors.

Dependent variable	Vehicle-trip
	Cargo weight
	Value
Independent variable	Employment
	Building area (square footage)
	Land Use
	Other economic data (sales, establishments, industry segments, type of business)
	Vehicle type
	Commodity type
	Other
Level of aggregation	Disaggregate
	Aggregate
Level of geography	Metropolitan
	Statewide
	National
	Corridor
	Special Facility (e.g. Ports)
Estimation technique	Trip - Growth rates
	Ordinary Least Squares (regression)
	Spatial regression
	Multiple Classification Analysis
	Time series
	Input-Output
	Neural Networks
	Others
Model structure	Linear
	Non-Linear

Copyright National Academy of Sciences. All rights reserved.

Copyright National Academy of Sciences. All rights reserved.

Table 67. FTG models classified by review factors.

		Dependent variable			Independent variable								Level of aggre-gation		Level of geography					Estimation technique									Model structure	
		Vehicle-trip	Cargo weight	Value	Employment	Square footage	Land Use	Trip data	Economic data	Vehicle type	Commodity flows	Other	Disaggregate	Aggregate	Metropolitan	Regional	National	Corridor	Special Facil. (i.e. Ports)	Trip - Growth rates	Ordinary Least Squares (regression)	Spatial regression	Mult. Class. Analysis	Trend and time series	Input Output	Neural Networks	Growth rates	Others	Linear	Non-Linear
NCHRP Synthesis 298	Lower Mainland Truck Freight Study	x			x						x			x		x													x	
NCHRP Synthesis 298	Denver Regional Council of Governments (DRCOG)	x						x	x							x														
NCHRP Synthesis 298	Development of a Statewide Truck Trip Forecasting Model Based on Commodity Flows and Input-Output Coefficients	x									x		x			x									x					
NCHRP Synthesis 298	Assessment of Market Demand for Cross-Harbor Rail Freight Service in the New York Metropolitan Region	x									x					x														
NCHRP Synthesis 298	Transport Flows in the State of Indiana: Commodity Database Development and Traffic Assignment: Phase 2	x			x						x					x					x				x					
NCHRP Synthesis 298	Multimodal Freight Forecasts for Wisconsin	x							x		x		x			x									x				x	
NCHRP Synthesis 298	Analysis of Freight Movements in the Puget Sound Region	x						x		x			x			x													x	
NCHRP Synthesis 298	Portland Commodity Flow Tactical Model System: Functional Specifications	x									x		x			x									x					
NCHRP Synthesis 298	The Second Generation Michigan Statewide Truck Travel Demand Forecasting Model	x			x				x				x			x				x					x				x	
NCHRP Synthesis 358	Virginia Freight Component	x									x			x		x														
NCHRP Synthesis 358	Wisconsin Freight Component	x			x						x			x		x					x									
NCHRP Synthesis 384	Atlanta (ARC) Commercial Vehicle and Truck Models	x			x		x							x		x					x								x	
NCHRP Synthesis 384	Baltimore Metropolitan Council (BMC) Models	x			x									x		x					x								x	
NCHRP Synthesis 384	Southeast Michigan's regional freight system	x			x	x								x		x				x	x									
NCHRP Synthesis 384	Los Angeles regional Cube Cargo Model	x			x		x							x		x					x									x
NCHRP Synthesis 384	New York Best Practice Model	x												x		x												x		
NCHRP Synthesis 384	Delaware Valley Regional Planning Commission Model	x							x				x			x							x						x	
NCHRP Synthesis 384	Maricopa Association of Governments MAG	x			x		x							x		x				x									x	

		Dependent variable			Independent variable							Level of aggre-gation		Level of geography					Estimation technique									Model structure	
		Vehicle-trip	Cargo weight	Value	Employment	Build. area (Sq.ft.)	Land Use	Other economic data	Vehicle type	Commodity type	Others	Disaggregate	Aggregate	Metropolitan	Statewide	National	Corridor	Special Facil. (i.e. Ports)	Trip Rates	Ordinary Least Squares (regression)	Spatial Regression	Mult. Class. Analysis	Time Series	Input Output	Neural Networks	Growth Rates	Others	Linear	Non-Linear
Jack Faucett Associates (1999)	Research and Development of Destination, Mode, and Routing Choice Models for Freight	x	x				x				x													x					
Cambridge Systematics (1996)	Quick Response Freight Manual (QRPM)	x						x					x	x															
Marker and Goulias (1998)	Truck Traffic Prediction Using the Quick Response Freight Model Under Different Degrees of Geographic Resolution: A GIS Application in Pennsylvania	x						x				x	x	x															
Garrido (2000)	Spatial interaction between trucks flows through the Mexico-Texas border	x																					x						x
FHWA (1999)	Guidebook on Statewide Travel Forecasting	x											x	x								x							
Bastida and Holguín-Veras (2009)	Freight generation models: comparative analysis of regression models and multiple classification analysis	x			x			x		x			x							x		x							
Brogan (1980)	Improving Truck Trip-Generation Techniques through Trip-End Stratification	x					x																						
Middleton et al. (1986)	Trip Generation for Special-Use Truck Traffic	x							x		x																		
Tadi and Balbach (1994)	Truck Trip Generation Characteristics of Nonresidential Land Uses	x					x		x																				
Wegmann et al. (1995)	Characteristics of Urban Freight System	x										x						x											
Guha and Walton (1993)	Intermodal Container Ports: Application of Automatic Vehicle Classification System for Collecting Trip Generation Data	x										x						x											
Holguín-Veras et al. (2002)	Truck-trip generation at container terminals	x											x																
Al-Deek et al. (2000)	Truck Trip Generation Models for Seaports with Container-Trailer Operations	x										x						x		x									
Bartlett and Newton (1982)	Goods vehicle trip generation and attraction by industrial and commeical premises	x			x	x							x		x						x							x	

(continued on next page)

Copyright National Academy of Sciences. All rights reserved.

Table 67. (Continued).

		Dependent variable			Independent variable							Level of aggre-gation		Level of geography					Estimation technique									Model structure	
		Vehicle-trip	Cargo weight	Value	Employment	Build.area (Sq. ft.)	Land Use	Other economic data	Vehicle type	Commodity types	Others	Disaggregate	Aggregate	Metropolitan	Statewide	National	Corridor	Special Facil. (i.e. Ports)	Trip rates	Ordinary Least Squares (regression)	Spatial Regression	Mult. Class. Analysis	Time Series	Input Output	Neural Networks	Growth Rates	Others	Linear	Non-Linear
Al-Deek (2001)	Comparison Between Neural Networks and Multiple Regression Approaches for Developing Freight Planning Models with Specific Applications to Seaports	x										x						x							x				x
Kawamura et al. (2005)	Business and Site specific trip generation methodology for truck trips	x			x	x						x																	
Novak et al. (2008)	Nationwide Freight Generation Models: A Spatial Regression Approach	x											x			x					x								
Maruyara and Harata (2005)	Incorporating Trip-Chaining Behavior into Network Equilibrium Analysis																												
Waliszewski et al. (2004)	Comparison of Commodity Flow Forecasting Techniques in Montana		x																							x			
Sorratini and Smith (2000)	Development of a Statewide Truck Trip Forecasting Model Based on Commodity Flows and Input-Output Coefficients		x					x																x					
Boyce (2002)			x							x			x		x									x					
Giuliano et al. (2007)	Estimating freight flows for metropolitan area highway networks using secondary data sources		x							x			x	x										x					
Fisher and Han (2001)	External Urban Truck Trips Based on Commodity Flows.		x										x	x										x					
Al-Battaineh and Kaysi (2005)	Commodity-based truck origin-destination matrix estimation using input-output data and genetic algorithms		x		x			x			x		x	x										x			x		
Sorratini (2000)	Estimation Statewide Truck Trips Using Commodity Flows and Input-Output Coefficients		x								x		x		x									x					
Hewings et al. (2002)	Combined model of interregional commodity flows on a transportation network		x							x			x		x									x					
Zhao and Kockelman, 2004	The Random-utility-based Multiregional Input-Output Model: Solution Existence and Uniqueness		x										x		x									x					
Ham et al. (2005)	Implementation and Estimation of a Combined Model of Interregional, Multimodal Commodity Shipments and Transportation Network Flows		x										x		x									x					

Copyright National Academy of Sciences. All rights reserved.

		Dependent variable			Independent variable							Level of aggre-gation		Level of geography					Estimation technique									Model structure	
		Vehicle-trip	Cargo weight	Value	Employment	Build area (Sq. ft.)	Land Use	Other economic data	Vehicle type	Commodity types	Others	Disaggregate	Aggregate	Metropolitan	Statewide	National	Corridor	Special Facil. (i.e. Ports)	Trip rates	Ordinary Least Squares (regression)	Spatial Regression	Mult. Class. Analysis	Time series	Input Output	Neural Networks	Growth rates	Others	Linear	Non-Linear
Iding et al (2002)	Freight trip generation by firms	x			x	x	x		x	x		x		x						x								x	
Taniguchi and Thompson (2002)	Modeling city logistics																												
Patier and Routhier, 2008	How to improve the capture of urban goods movement data																												
Russo and Comi (2002)	Urban Freight Movement: a quantity attraction model	x	x		x			x		x		x							x					x			x		x
Routhier et al (2002)	Mesurer l'impact du transport de marchandises en ville: le modèle de simulation FRETURB v1.	x																											
Wagner (2010)	Regional traffic impacts of logistics-related land use	x			x	x	x					x		x						x								x	
DeVries and Dermisi (2008)	Regional Warehouse trip production analysis: Chicago Metro Analysis	x			x	x	x					x		x													x	x	
Orsini et al. (2009)	Logistics Facilities impacts on the territory, Ratio for French warehouses	x			x	x	x					x						x		x								x	
Bröcker (1998)	Regional/national SCGE model			x				x					x			x								x			x		x
Tavasszy et al (1998)	Multistep freight model	x	x	x	x		x	x	x	x			x			x								x		x	x		x
Oosterhaven et al. (2001)	Regional/national SCGE model			x			x	x					x			x								x			x		x
WSP (2005)	Multistep freight model	x	x	x	x		x	x	x	x			x			x								x		x	x		x
Ivanova et al. (2002)	Regional/national SCGE model			x			x	x					x			x								x			x		x
Gentile and Vigo (2009)	Movement generation and trip distribution for freight demand modeling applied to city logistics	x			x							x	x	x								x					x	x	
Swahn (2001)	Multistep freight model	x	x	x	x		x	x		x			x			x								x		x	x		x
Al-Deek (2001)	Regression Analysis Model for the port of	x									x	x						x							x				x
Al-Deek et al. (2002)	BPN Model to Port of Everglades	x									x	x						x							x				x

(continued on next page)

Copyright National Academy of Sciences. All rights reserved.

Table 67. (Continued).

		Dependent variable			Independent variable							Level of aggre-gation		Level of geography					Estimation technique									Model structure	
		Vehicle-trip	Cargo weight	Value	Employment	Build.area (Sq. ft.)	Land Use	Other economic data	Vehicle type	Commodity types	Others	Disaggregate	Aggregate	Metropolitan	Statewide	National	Corridor	Special Facil. (i.e. Ports	Trip Rates	Ordinary Least Squares (regression)	Spatial regression	Mult. Class. Analysis	Time Series	Input Output	Neural Networks	Growth Rates	Others	Linear	Non-Linear
NCHRP Syn. 606	Heavy Truck Freight Model for Florida Ports	x									x		x					x		x			x						x
NCHRP Syn.606	Cross-Cascades Corridor Model	x			x							x					x							x				x	
NCHRP Syn.606	Minnesota Truck Highway 10 Truck Trip Forecasting Model	x			x							x					x		x									x	
NCHRP Syn.298	New York Metropolitan Region Model (Freight tunnel)		x							x	x	x					x												
NCHRP Syn.384	Atlanta Commercial Vehicle and Truck Models	x			x			x					x	x						x								x	
NCHRP Syn.384	Baltimore Metropolitan Council Models	x			x			x					x	x						x								x	
NCHRP Syn.298	Bangor Area Model	x			x			x			x		x	x														x	
NCHRP Syn.298	Chicago Commercial Vehicle Travel Demand Model	x			x								x	x					x									x	
NCHRP Syn.384	Delaware Valley Regional Planning Commission Model	x										x		x								x						x	
NCHRP Syn.298	Denver Regional Model	x												x															
NCHRP Syn.298	Greater Buffalo–Niagara Regional Model	x			x		x	x				x		x					x									x	
NCHRP Syn.384	Los Angeles Regional Cube Cargo Model (2004)		x		x								x	x						x				x				x	
NCHRP Syn.384	Maricopa Association of Governments Model	x			x		x	x				x		x					x									x	
NCHRP Syn.384	New York Best Practice Model	x											x	x													x		
NCHRP Syn.298	Portland Commodity Flow Tactical Model System		x										x	x															
NCHRP Syn.298	Puget Sound Region Freight Model		x		x					x		x		x															
NCHRP Syn.298	Skagit Countywide Model		x									x		x															
NCHRP Syn.606	Southern California Association of Governments Heavy Truck Model	x	x		x		x	x				x		x								x		x				x	
NCHRP Syn.298	Vancouver Truck Freight Model	x			x			x			x	x		x															
NCHRP Syn.298	San Francisco Bay Area Freight Model	x			x								x	x						x								x	
NCHRP Syn.384	Southeast Michigan's Regional Freight System	x			x	x		x					x	x					x	x								x	
NCHRP Syn.298	Connecticut Model		x												x														
NCHRP Syn.606	Florida Intermodal Statewide Highway Freight Model		x		x			x				x			x					x								x	
NCHRP Syn.298	Florida Model (2001)		x		x			x				x			x					x									
NCHRP Syn.606	Indiana Commodity Transport Model (1993)		x		x			x				x			x					x								x	

Copyright National Academy of Sciences. All rights reserved.

		Dependent variable			Independent variable							Level of aggre-gation		Level of geography					Estimation technique									Model structure	
		Vehicle-trip	Cargo weight	Value	Employment	Build.area (Sq. ft.)	Land Use	Other economic data	Vehicle type	Commodity types	Others	Disaggregate	Aggregate	Metropolitan	Statewide	National	Corridor	Special Facil. (i.e., Ports)	Trip Rates	Ordinary Least Squares (regression)	Spatial Regression	Mult. Class. Analysis	Time Series	Input Output	Neural Networks	Growth Rates	Others	Linear	Non-Linear
NCHRP Syn.298	Indiana Commodity Transport Model (1997)		x		x						x				x					x				x					
NCHRP Syn.298	Kansas Model		x												x														
NCHRP Syn.298	Kentucky Model		x												x												x		
NCHRP Syn.298	Massachusetts Statewide Model		x								x				x														
NCHRP Syn.298	Michigan Statewide Truck Travel Demand Forecasting Model		x		x										x									x				x	
NCHRP Syn.298	Multimodal Freight Forecasts for Wisconsin (1996)		x										x		x									x					
NCHRP Syn.606	New Jersey Statewide Model Truck Trip Table	x			x			x			x		x		x					x									x
NCHRP Syn.298	New South Wales Australia Model		x												x									x					
NCHRP Syn.298	North Carolina Model	x			x										x														
NCHRP Syn.298	Ohio Model	x			x										x					x									
NCHRP Syn.298	Oregon Model		x												x									x					
NCHRP Syn.358	Virginia Freight Model	x	x		x			x					x		x												x		
NCHRP Syn.358	Wisconsin Statewide Freight Component (2006)		x		x			x			x	x			x					x									
NCHRP Syn.298	Wisconsin Statewide Truck Trip Forecasting Model (2000)		x												x									x					

Copyright National Academy of Sciences. All rights reserved.

Table 68. Model characteristics by level of geography.

Geography	Number of cases	Dependent Variables				Independent Variables							Aggregation Level		Modeling Technique									Structure	
		Vehicle trip	Commodity flow	V&C Combination	Value	Employment	Build. area (Sq. ft.)	Land Use	Other economic data	Vehicle type	Commodity type	Others	Disaggregate	Aggregate	Trip Rates	Ordinary Least Squares (regression)	Spatial Regression	Mult. Class. Analysis	Time Series	Input Output	Neural Networks	Growth Rates	Others	Linear	Non-linear
F & C	11	10	1			3	1	1			1	4	10	1	1	3			1	1	3			3	4
M	27	19	7	1		17	4	6	11	1	3	3	12	16	4	7		4		5			4	15	
S	24	4	19	1		11	1		6		2	5	4	9		7	1			11			2	4	1
N	7	1		3	6	3		5	6	2	3			7			1			6		3	6		6
Total	69	34	27	5	6	34	6	12	23	3	9	12	26	33	5	17	2	4	1	23	3	3	12	22	11

Note: F & C: Facility and Corridor; M: metropolitan; S: Statewide; N: National

In terms of the dependent variable, 47% use vehicle trips; 38% use commodity tonnage; and 15% use a combination of vehicle trips (usually for internal-internal trips); and commodity tonnage (for the rest of the flows). About 38% of the models are aggregated, 48% are disaggregated, and others (14%) cannot be derived from the review. The independent variables used include: employment by industry sector (49%); building area (9%); commodity type (13%); land use (2%); and other variables (27%). As for modeling techniques: 25% use least square; 10% use trip rates; 6% use multi-classification analysis; and 33% use IO analysis. These three modeling methods constitute the majority of FTG models used in practice (or about 74%). In addition, from the model information that is known, most of the models are linear (22 out of 33), while a small fraction are nonlinear.

Review of FG/FTG Models

This section reviews some key publications. The models are grouped into vehicle-trip-based models and commodity-based models. The section is followed by descriptions of the advantages and disadvantages of the different modeling techniques.

Trip-Based Models

The FHWA *Guidebook on State Travel Forecasting* (Federal Highway Agency 1999) uses land use and trip data from travel diaries and shipper behavior to estimate truck trips; these are then distributed using a form of gravity models that are calibrated with trip length frequency distributions obtained from trip diaries. Another trip-based model, the *Quick Response Freight Manual* (Cambridge Systematics Inc. 1996), calculates the number of commercial vehicle trips at the zonal level, commercial vehicle volumes at external stations, and commercial trips between zones, by applying trip generation rates using economic activity data for the traffic analysis zone. After the trips have been estimated, the model uses mode shares for each trip and then loads the O-D matrix to the network. The estimated vehicle miles traveled (VMT) were compared with control VMT for calibration. This model was implemented in a truck flow survey study that investigated the effects on traffic assignment when using different degrees of geographic resolution (Marker and Goulis 1998). The study showed that applying a very aggregated model (e.g., the one suggested by the *Quick Response Freight Manual)* to a study area using extremely disaggregated Travel Analysis Zones (TAZs) results in no noticeable loss in model accuracy.

The ITE *Trip Generation Manual,* 8th Edition (Institute of Transportation Engineers 2008) contains a comprehensive compilation of estimated FTG rates for a broad range of land use types. Although the focus of the ITE Manual is on all vehicle types, some of the results can be applied directly to FTG, e.g., truck terminals. The ITE *Trip Generation Handbook,* 2nd Edition, provides guidelines on how these rates (for all vehicle types) may be used for a given trip generation study. Appendix A of the ITE Handbook provides some information on truck trip generation. The Appendix also provides a number of cautionary notes to keep in mind when conducting FTG studies. The most noticeable ones are related to the need to: use consistent definitions of trucks and truck trips; consider the age of the existing FTG data; avoid land use classes that are too broadly defined; and think carefully about the selection of independent variables.

Iding et al. (2002) estimated linear regression models of truck trip generation at industrial sites. The sample included 1,529 firms within the Netherlands with more than 5 employees. Parameters (slope and intercept) were obtained for two

Copyright National Academy of Sciences. All rights reserved.

different classification types (18 sectors and 5 types of heavy industry site) and two independent variables (area and employment). The results indicate that which independent variable is better depends on the industry sector and on the direction of freight (in- or outbound). The logistics and transport services sector was found to have the highest average level of outbound trips produced.

Other vehicle trip models estimate FTG rates for productions and attractions using cross classification [Bastida and Holguín-Veras (2009) compared the use of cross classification and OLS for FTG modeling]. The authors estimated disaggregated freight trip delivery rates taking into consideration company attributes. Using cross classification analysis, the authors identified the groups of company attributes that best explain FTG. When using linear regression models, the authors identified that commodity type, industry segment, and employment are strong predictors for FG. Brogan (1980) analyzed different stratification strategies for improving trip-end generation models, identifying land use as the most effective stratification scheme for improving model significance. Middleton et al. (1986) analyzed trip generation characteristics for special land use truck traffic in Texas; their study included an assessment of each special land use class in terms of FTG. Data collected included trip generation rates, trip length and vehicle type. Tadi and Balbach (1994) estimated trip generation rates based on vehicle type stratification for nonresidential land uses in Fontana, California; traffic counts were used on their estimations. Kawamura et al. (2005) took into consideration the supply chain decisions made by individual businesses in the estimation of FTG. Among other findings, the authors concluded that store floor space and the number of employees are poor indicators of truck trips at retail stores. At the city level, different freight models were developed in Europe that include some form of trip generation modeling [see Taniguchi and Thompson (2002) and Patier and Routhier (2008) for overviews]. Models are generally linear and based on zonal aggregates or survey data. Examples are Russo and Comi (2002) for Italy, and Routhier et al. (2002) for France.

FTG models of various kinds have been developed for special facilities such as ports (Guha and Walton 1993; Wegmann et al. 1995; Holguín-Veras et al. 2002). Al-Deek et al. (2000) and Al-Deek (2001) used regression analysis and neural networks respectively to develop trip generation models. Wagner (2010) carried out an analysis of trip generation around the port of Hamburg, Germany. Regional warehouse trip production rates were published in DeVries and Dermisi (2008) for the Chicago metro area, and in Orsini et al. (2009) for France.

Other methodologies that have been implemented for production and attraction include: time series models, IO, and related models. Time series data have been used to develop models that range from growth factor models to auto-regressive moving average models (Garrido 2000). Sorratini (2000) estimated truck flows for the state of Wisconsin, using data from the 1993 CFS and IO coefficients. The authors derived production and attraction rates in tons for heavy truck mode for 28 economic sectors; the annual tons for the county level were converted to daily truck trips using average tons-per-vehicle load factors. The trips were then assigned to the network and the results were compared to real counts. It was found that the production and attraction values were underestimated since not all truck trips were included. Bartlett and Newton (1982) studied FTG using regression models based on four independent variables: total employment, site area, gross floor area, and non-office employment. The firms were grouped based on FG intensity. It was found that the model results matched very well with actual vehicle-trip counts. It was also found that haulage firms, fuel distributors, waste disposal firms, and ready-mix concrete/bulk distribution firms were the most intensive generators, while manufacturers and printers were the least intensive. Freight generation intensity, however, varies significantly within the same industry sector.

Commodity-Based Models

Waliszewski et al. (2004) estimated zonal commodity generation using commodity-type specific growth rates and assumed that land use characteristics do not change over time. Novak et al. (2008) estimated FG at the national level, using commodity flow data using spatial regression methodologies. These models explicitly consider the spatial autocorrelation among variables based on spatial proximity. The authors found that the spatial autocorrelation violates the independence assumption usually imposed by ordinary linear regression models but contains valuable information that can improve model fit. The authors concluded that at the national level, spatial regression is the preferred specification for FG.

Input-output (IO) models are generally implemented for large-scale systems at the regional, national or international level, since they require a great amount of data on regional economic activity and interregional flows. They have been used to estimate commodity-based generation models (Sorratini and Smith 2000). These models are basically macroeconomic models that start from IO tables, which describe, in monetary units, what each sector of the economy delivers to the other sectors. Boyce (Boyce 2002) formulated and analyzed a model of interregional commodity flows, incorporating regional IO relationships and the corresponding transportation network flows. Using a local-area IO model combined with import-export commodity flow data from secondary sources, Giuliano et al. (2007) estimated intra-metropolitan freight flows on a highway network. Al-Battaineh and Kaysi (2005) used IO data with employment and population information to estimate commodity production and attraction

Copyright National Academy of Sciences. All rights reserved.

at the zonal level. Interregional commodity flows have been formulated and analyzed incorporating regional IO relationships and the corresponding transportation network flows (Hewings et al. 2002). Zhao and Kockelman (2004) not only estimate freight traffic generation and attraction, but also the flows between regions and the mode share using interregional versions of IO models.

In Europe, commodity-based freight models are operational in several countries. Most of these start from IO tables or Make/Use tables (IO tables that include an additional segmentation of type of goods). Value-to-weight ratios and regional employment statistics are used to convert macro level IO data to regional commodity flow data. Trip generation rates are, to an increasing degree, becoming endogenous variables in these commodity-based freight models, either implemented as variants of the Lowry type land use–transportation interaction (LUTI) models, or as advanced Spatial Computable General Equilibrium (SCGE) models. Several countries in Europe (and the United States and Canada) have transferred their freight models from IO-based, fixed coefficient models to flexible coefficient models, either in the shape of LUTI or of a full SCGE model. For a broad inventory of international experiences in integrative commodity-based trip generation and distribution modeling, the reader is referred to Tavasszy et al. (1998). Examples include the Dutch freight models SMILE and RAEM (Tavasszy et al. 1998; Oosterhaven et al. 2001); the UK Freight model (WSP Policy & Research 2005), the Swedish freight model SAMGODS (Swahn 2001), the Norwegian model PINGO (Ivanova et al. 2002) and the German SCGE model, which later became known as CGEurope (Bröcker 1998).

Review of TRB Synthesis Reports

FTG has been a focus of several NCHRP studies including *NCHRP Synthesis 298, NCHRP Synthesis 384, NCHRP Synthesis 358, NCHRP Synthesis 606, NCHRP Synthesis 410,* and *NCHRP Report 404.* Brief summaries of these studies are provided in this section.

NCHRP Synthesis 298: Truck Trip Generation Data

The synthesis report mainly identifies available data sources and data collection techniques, and assesses the current state-of-the-practice in truck trip generation. The report discusses key considerations in the development of truck trip generation data needs, which include uses of truck trip generation data, trip purposes, estimation techniques, and data collection. Two types of trip generating models are discussed: vehicle-based models and commodity-based models. Twelve vehicle-based travel demand models and 14 commodity-based travel demand models were presented. The report also reviews numerous projects related to FTG, especially on the topics of truck trip generation data needs and survey methods. It lists three major methods to estimate truck trip generation data: estimation of simple rates, linear regression models, and commodity flow models. In Chapter Three of the report, data sources that were used to estimate truck trip generation in practice are compiled. This report also summarizes seven most commonly used approaches to collecting data for truck trip generation, including trip diaries; classification counts; published commodity flow data; collected commodity flow data; shipper/carrier/special generator surveys; intercept surveys; and published rates.

NCHRP Synthesis 384: Forecasting Metropolitan Commercial and Freight Travel

The report reviews methods of freight and commercial vehicle forecasting in practice, together with promising methods emerging from ongoing research. The primary focus of the report is on metropolitan-level forecasting, although some consideration is also given to statewide freight forecasting models. The report reviews application of the four-step model process to freight demand modeling, including the process of FTG. Major sources of planning information for freight and commercial vehicle forecasting are presented in this report. Besides the four-step model process, the report also summarizes seven emerging methods in freight demand models: time series modeling of freight traffic growth; behaviorally focused demand models; commodity-based forecasts, including interregional I-O models; methods that forecast flows over multimodal networks; micro-simulation and ABS techniques; and models that incorporate supply chain/logistics chain considerations. The report also lists several methods acquiring FTG results, including developing truck trip generation rates, borrowing trip rates from one or more other regions, introducing special generators, and using external stations. On urban freight data collection, the report presents two major methods: vehicle classification counts; and origin-destination surveys, which include roadside intercept surveys, mail and telephone surveys, establishment surveys, and carrier surveys.

NCHRP Synthesis 358: Statewide Travel Forecasting Models

The report examines statewide travel forecasting models, including passenger vehicles and freight components. It reviews the types and purposes of models being used. Data requirements, survey methods, funding, and staff resources are also reviewed to investigate the limitations and benefits of the models. In the survey of statewide freight forecast-

Copyright National Academy of Sciences. All rights reserved.

ing practice, the report defines two fundamentally different styles of freight forecasting: Direct forecast of vehicle flows without reference to commodities; and forecasting of commodities, then using the commodity flow forecast to estimate vehicle flows. The report includes five case studies: two are on freight components, including the Virginia freight component and the Wisconsin freight component; two are on passenger components; and one is a combined passenger and freight component. The report concludes that most statewide models are similar in structure to four-step urban transportation planning models, and that there exists no well-accepted definition of best practice in statewide models. The report points out several distinct trends in recent statewide model development, such as the emergence of commodity-based models, and more effective use of GIS to manage data, among others.

NCHRP Synthesis 606: Forecasting Statewide Freight Toolkit

This report presents an analytical framework for forecasting freight movements at the statewide level to develop forecasting models. The framework includes a tool kit of data collection techniques, analytical procedures, and computer models. It includes management approaches, decision-making procedures, and performance evaluation methods, which help improve statewide transportation under the increment of freight demands. The report also summarizes several classes of data sources, including model development (local and national surveys, compilations); flow conversion (tons to vehicles and tons to value); network data (modal network and intermodal terminals); forecasting data (population and employment); validation data; and classification schemes (commodity classification and industry classification). Meanwhile it presents five forecasting models and performance measures. Ten case studies of statewide freight modeling projects are reviewed, including FTG models, and model application and validation.

NCHRP Project 08-36/Task 79, "Scoping Study for a Freight Data Exchange Network"

This report investigates the feasibility of building a freight data exchange network to provide access to higher quality freight data. It considers a centralized data repository from which data providers and users can access freight datasets, metadata, or reports of data quality. In this network, data providers can upload data while end-users can download them in the form of summary tables, reports, and customized tabular data. The report describes various types of freight-related datasets, and suggests potential ways to utilize them, including the CFS, Rail Waybill Data, foreign trade data, Freight Analysis Framework 2 (FAF2), TranSearch Commodity Flows Database, freight databases from local and regional studies, socio-economic data from regional studies, and other data sources. It also conducted interviews with potential data users and providers.

NCHRP Synthesis 410: Freight Transportation Surveys

This review examines the sample size, data accuracy, data comprehensiveness, and survey objectives for freight transportation. It also includes a discussion of the feasibility and benefits of linking survey data with data from roadway and sensors.

NCHRP Report 404: Innovative Practices for Multimodal Transportation Planning for Freight and Passengers

This report reviews innovative agency practices and methods in multimodal planning. The report monitors the performances of public involvement planning effects on rural areas of the studied cases. It also mentions fiscal constraints in planning and programming.

Comparison of FTG Methods and Models

Table 69 presents a summary of the advantages and disadvantages of various methods and models used to estimate freight transport production and attraction. The table combines the review results in Jong et al. (2004) and those in Bastida and Holguin-Veras (2009).

Summary

This section summarizes the findings of conducting the literature review regarding FG and FTG models.

The Bulk of the Studies Have Focused on FTG, Not FG. As illustrated in the literature review, the bulk of the models are based on vehicle trips, though a handful of studies consider FG in the context of IO models. This stands in contrast with European practices that emphasize commodity-based approaches that incorporate FG modeling as an endogenously determined variable.

It is Not Yet Clear Which Modeling Techniques Are the Best. Although extensive research has been conducted in the last several decades on developing FG/FTG, there is no study to compare specifically the performances of these techniques; there is no consensus yet regarding which models

Copyright National Academy of Sciences. All rights reserved.

Table 69. Advantages and disadvantages of FG/FTG models.

Type of model	Advantages	Disadvantages
Time series	Require multiple data points over time for the same facility. Limited data requirements for independent variables.	Little insight into causality and, limited possibility to study policy effects
Trip rates	Simple to calculate	Unable to connect the effect of business size on FTG which may lead to significant errors
	Limited data requirements (zonal data)	Little insight into causality and, limited scope for policy effects
Input-output	Linked to the economy	Need input-output table, preferably multi-regional
	Can give land use interactions	Need to identify import and export trade flows
	Policy effects could be considered if coefficients are elastic	Restrictive assumptions if fixed coefficients
		Need conversion from values to tonnes
Ordinary Least Squares (regression)	Able to identify not so obvious relations pertaining to demand generation; can be used not only to forecast future demand, but also to establish the dynamics between variables	Violations of the Ordinary Least Square (OLS) assumptions could lead to inaccurate parameters; especially using aggregated data
Spatial regression	Improve model fit; eliminate problems associated with the spatial autocorrelation	Choice of a spatial model depends on actual data and it is hard to pre-determine which structure is more appropriate
Multiple Classification Analysis	Can overcome the disadvantages associated with cross classification analyses	May overestimate the future number of trips if the number of observations by category is not exactly the same
Neural networks	Can produce accurate results; do not need to preselect independent variables; the learning capability of the model can discover more complex and suitable interactions among the independent variables.	Need a sizeable database to develop and calibrate the model

can produce the most accurate results. This is reflected by the fact that different agencies are applying a variety of different freight (trip) generation models (see Appendix E) due to the lack of a commonly agreed upon "best practice" model. However, based on previous research experiences, the research team does believe that certain modeling techniques, such as disaggregated models and regression analysis, have advantages that stand out among all modeling techniques.

There Are No Consistent Definitions of Trucks, Truck Trips, and Land Use Classes. The lack of consistent industry terms is a point made by the ITE *Trip Generation Handbook,* and other publications. The inconsistent definitions of these important variables contributes to shaky results regarding which factors are the most important in explaining FG/FTG, and which modeling techniques are most effective. There is thus a need to standardize these definitions so that more consistent FG/FTG modeling approaches could be developed.

Copyright National Academy of Sciences. All rights reserved.

APPENDIX E

Description of Practice, Evaluation Criteria, and Evaluation Process

This chapter describes the current practices, both domestic and international, of FG and FTG modeling. The different modeling applications of FG and FTG modeling are classified (Fischer and Han 2001) as follows:

- **Planning applications:** The main goal here is to produce estimates of FG/FTG for conglomerations of users—typically defined by a zoning system—for transportation planning purposes at the state, regional, corridor, or urban level. Typically, these are medium- and long-term studies aimed at answering questions about medium/long-term capacity needs and economic development.
- **Engineering applications:** These analyses are intended to provide key input to a variety of engineering design questions concerning facility design issues, traffic operation studies, site impact analyses, provision of on/off-street parking for trucks, etc. In some cases, the analysis could focus on a single establishment, a single location with multiple establishments, or an entire area, such as a downtown area. These studies emphasize short-term analyses and improvements.

State-of-Practice of Transportation Planning Applications

Describing the current practices of FG/FTG modeling requires contending with the multitude of modeling possibilities, and the lack of an accepted modeling standard. In order to simplify the problem, the team decided to focus on the specific functions that each model component is expected to perform—as opposed to focusing on the modeling techniques themselves. Doing this provides a clear and succinct way to discuss the role of FG/FTG modeling in the context of planning applications. Figure 17 shows the main outputs of the different components of freight demand models used in transportation planning. As shown in the figure, there are multiple paths—represented by the arrows—that could be taken that reflect the options available to the analyst. It is important to highlight that each of these decisions have implications in subsequent steps. For example, deciding to model vehicle trips will lead to a situation in which freight mode/vehicle choice cannot be considered for the simple reason that the vehicle trips are themselves already the output of a freight mode/vehicle choice that already took place. Similarly, while producing an economic forecast of employment could be mapped into the corresponding land uses, typically the reverse cannot be done because land use is a composite of disparate industry sectors. Data collection efforts also constrain the kind of models that could be developed. For example, if commodity flow data are not collected or available, then the only alternatives are the vehicle-trip formulations shown in the right side of the figure.

It should be said that, although Figure 17 represents the entire freight demand modeling process, the main emphasis here is on those aspects that concern FG/FTG analyses, which are represented by the dotted box in the figure. In this context, the FG/FTG literature is discussed and classified with respect to the:

- **Dependent variable:** This is the output of the modeling effort, which could be commodity tonnage (C); vehicle trips (V); or a mix of commodity tonnage and vehicle trips (C&V). The latter represents cases where an internal truck-trip origin-destination matrix is estimated for internal-internal trips, and a commodity-based model is used for external-internal and internal-external trips.
- **Independent variables:** These are the variables used to explain FG or FTG. They typically are employment, population, land use, etc.
- **Level of aggregation:** This refers to the level of detail used in the model. Aggregate (A) models quantify the FG and FTG of a conglomeration of users while Disaggregate (D) models study the FG and the FTG patterns of individual establishments.

Copyright National Academy of Sciences. All rights reserved.

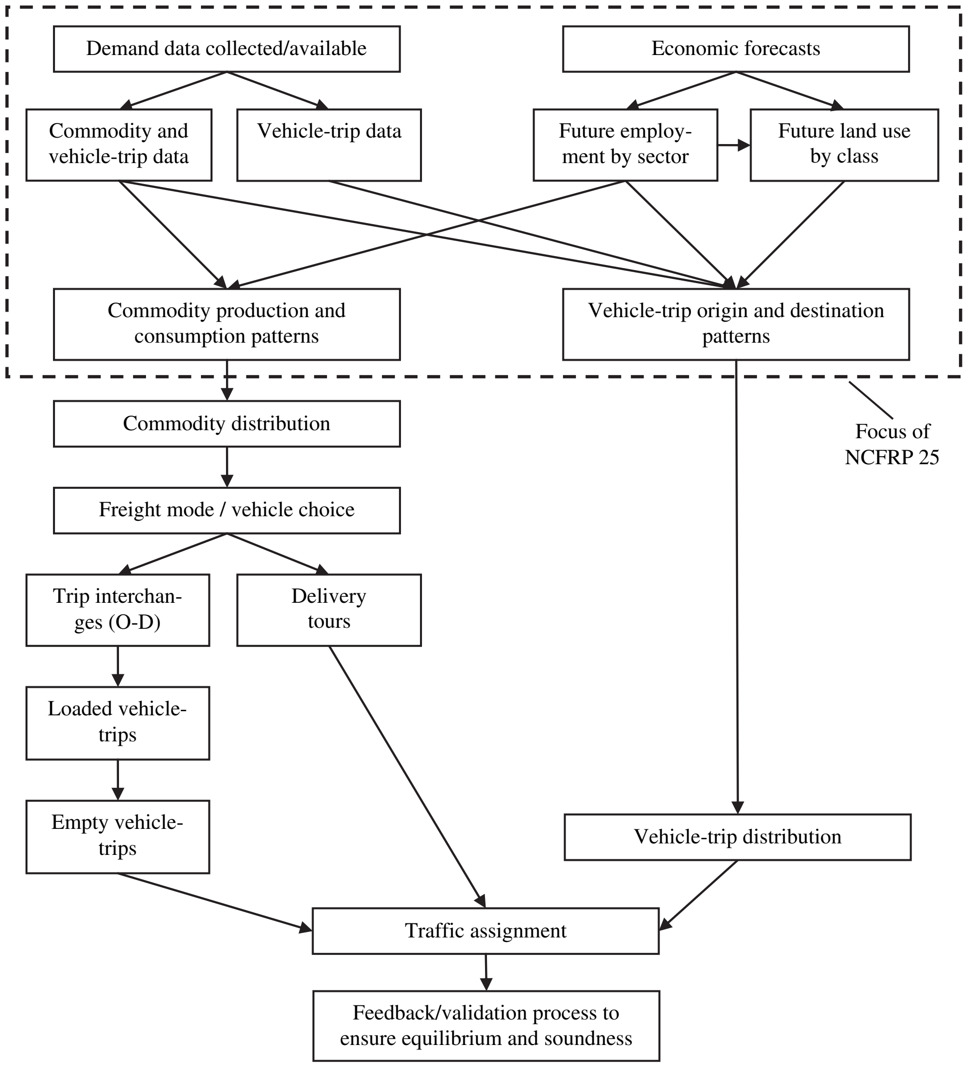


Figure 17. Schematic of modeling pathways.

- **Level of geography:** Five cases are considered: Facility specific (F); Corridor (C); Metropolitan (M); Regional (R); and State (S).
- **Data sources used:** The input used in the modeling effort.

Review of Domestic Practice

The review is based on previous publications and additional modeling applications identified by the team. This review, while by no means comprehensive, provides a solid overview of the state of domestic practice on FG and FTG planning applications. A summary of the models is presented in Table 70. To facilitate interpretation and analysis, the bulk of the modeling applications are at the state level (46%), and metropolitan areas (44%). Corridor and facility specific applications represent the remaining 10%. It is important to highlight that Table 70 only contains the applications for planning purposes, which explains the low number of facility specific examples as most of them are done for engineering applications (discussed in the next chapter).

In terms of the dependent variable: 46% use vehicle trips; 49% use commodity tonnage; and 5% use a combination of vehicle trips (usually for internal-internal trips), and commodity tonnage (for the rest of the flows). About 33% of the models are aggregated, 36% are disaggregated, and others (31%) could not be identified from the review. The independent variables used include: employment by industry sector (62% of cases); population (36%); land use variables (5%); and other variables (23%). As for modeling techniques, 33% use regression analysis, 23% use IO analysis, and 13% use FTG rates. These three modeling methods constitute the majority of the FTG models used in practice (about 69%). Other methods include cross classification (5%), matrix estimation (8%), and time series analysis (1%). No information could be obtained for the remaining 17%. The bulk of the models reported in the literature are linear (16 out of 18).

Copyright National Academy of Sciences. All rights reserved.

Table 70. Summary of modeling applications.

Models	Dependent Variables	Independent Variables	Aggre-gation	Geogra-phy	Modeling Technique	Structure	Data Sources
Heavy Truck Freight Model for Florida Ports	V	Month index, exported and imported freight units	A	F	Time series, regression	N	Gate/vessel/container data, gantry crane data, and performance reports
Cross-Cascades Corridor Model	V	Employment by sector	D	C	IO	L	State population survey, Census data, Transearch
Minnesota Truck Highway 10 Truck Trip Forecasting Model	V	Employment by sector	D	C	FTG rates	L	Truck data, Industrial employment, Quick Response Freight Manual
New York Metropolitan Region Model (Freight tunnel)	C	Truck payload factors by commodity group	D	C			Transearch
Atlanta Commercial Vehicle and Truck Models	V	Industrial, retail, office employment, households	A	M	Regression	L	Truck survey data and counts
Baltimore Metropolitan Council Models	V	Industrial, retail, office employment, households	A	M	Regression	L	Truck survey, borrowed FTG rates
Bangor Area Model	V	Employment, population, industrial productivity	A	M		L	Industrial productivity gains, Quick Response Freight Manual
Chicago Commercial Vehicle Travel Demand Model	V	Employment by sector	A	M	FTG rates	L	Commercial Vehicle Survey, trip diaries
Delaware Valley Regional Planning Commission Model	V		D	M	Cross-classification	L	Socioeconomic data, truck survey
Denver Regional Model	V			M			Trip diaries, intercept surveys, and automatic vehicle counts
Greater Buffalo–Niagara Regional Model	V	Employment, population, land use	D	M	Land use FTG rates	L	Trip diaries, land use at trip end, carriers survey
Los Angeles Regional Cube Cargo Model (2004)	C	Employment	A	M	IO, regression	L	Socioeconomic, truck/commodity flow, and port data, intermodal-warehouse survey
Maricopa Association of Governments Model	V	Population, employment by land use category	D	M	Land use FTG rates	L	Truck survey, external vehicle trip survey, traffic counts.
New York Best Practice Model	V		A	M	OD estimation		Employment data, highway and transit counts, regional trip generation rates
Portland Commodity Flow Tactical Model System	C		A	M			Truck counts taken around truck terminals and reload facilities
Puget Sound Region Freight Model	C	Tonnage shipment rates by commodity, employment	D	M			County business patterns data, SAIC/ Transmode data, national IO tables
Skagit Countywide Model	C		D	M			Local economic data, surveys
Southern California Association of Governments Heavy Truck Model	V & C*	Land uses/Industry types, employment, household	D	M	IO, Cross classification	L	Shipper-receiver survey, IO tables, socioeconomic data, WIM data
Vancouver Truck Freight Model	V	Population, employment, special generator	D	M			Expanded origin–destination surveys, cargo volumes
San Francisco Bay Area Freight Model	V	Employment	A	M	Regression	L	Business survey, external intercept surveys, trip diaries
Southeast Michigan's Regional Freight System	V	Total/employment acres, basic, retail, wholesale employment, households	A	M	FTG rates, regression	L	Travel Survey Data
Connecticut Model	C			S			Transearch
Florida Intermodal Statewide Highway Freight Model	C	Employment by industry, population	D	S	Regression	L	Census of population, Transearch
Florida Model (2001)	C	Employment, population	D	S	Regression		Transearch, payload data, IO table
Indiana Commodity Transport Model (1993)	C	Employment, population	D	S	Regression	L	Socioeconomic data, employment and population forecasts, county business patterns data
Indiana Commodity Transport Model (1997)	C	Employment by industry, payloads, average percent empty by truck type		S	IO, regression		Commodity survey, commodity groups, mail data, truck payload data
Kansas Model	C			S			Local agricultural production data
Kentucky Model	C			S	OD estimation		Transearch, truck traffic counts
Massachusetts Statewide Model	C	Truck payload factor		S			Commodity flow survey, truck payload data
Michigan Statewide Truck Travel Demand Forecasting Model	C	Employment		S	IO	L	Employment data by industry, national IO tables

(continued on next page)

Copyright National Academy of Sciences. All rights reserved.

Table 70. (Continued).

Models	Dependent Variables	Independent Variables	Aggre-gation	Geography	Modeling Technique	Structure	Data Sources
Multimodal Freight Forecasts for Wisconsin (1996)	C		A	S	IO		Transearch, Census of manufacturers, value of shipment data
New Jersey Statewide Model Truck Trip Table	V	Employment, households, truck terminals, special generators	A	S	Regression	N	Commodity flows and survey data, truck counts data, Census Bureau data
New South Wales Australia Model	C			S	IO		Commercial vehicle and economic survey
North Carolina Model	V	Employment		S			trip diary surveys
Ohio Model	V	Employment		S	Regression		
Oregon Model	C			S	IO		Surveys
Virginia Freight Model	V & C*	Employment by industry group, population	A	S	OD estimation		Transearch, IO tables, employment, population
Wisconsin Statewide Freight Component (2006)	C	Employment by industry, population, trip generators	D	S	Regression		Transearch, national IO table, zonal employment and population
Wisconsin Statewide Truck Trip Forecasting Model (2000)	C			S	IO		Transearch, commodity flow survey

Table 71 summarizes the features of the various modeling approaches by level of geography. As shown, the bulk of the metropolitan-level planning applications use vehicle trips as the dependent variable, while statewide applications favor commodity flows. This undoubtedly reflects the inherent difficulties of collecting commodity flow data in urban areas, and the presence of the Transearch database at the core of the statewide models based on commodity flows. In all other respects, metropolitan and state FG/FTG applications are quite similar. (Not much should be made of the apparent difference in the aggregation level used, because of underreporting.) The table also shows that facility specific and corridor applications are in the minority.

Review of International Practice

Table 72 shows a summary of international modeling applications, mostly from Europe. Table 73 presents a summary of the models by level of geography. The table shows that most models are based on economic principles (e.g., IO, multi-regional IO, general equilibrium, SCGE). These techniques comprise 13 out of 23 applications. They are followed by regression models that capture 10 out of the 23 cases listed. It is interesting to note that none of the models listed use FG/FTG rates. Equally significant is that a sizable portion of the application listed is based on freight data collected through surveys. This stands in contrast with the United States, where freight data collection activities have dwindled since the 1980s.

State-of-Practice of Transportation Engineering Applications

This chapter discusses the application of FG/FTG to support transportation engineering applications (e.g., traffic impact fee assessment, traffic operations studies, site impact analysis, street design, etc., as summarized in *NCHRP Synthesis*

Table 71. Modeling applications by level of geography.

Geography	Number of cases	Dependent Variables			Independent Variables				Aggregation Level		Modeling Technique						Structure	
		Vehicle trip	Commodity flow	V&C Combination	Employment	Land use variables	Population	Others	Aggregate	Disaggregate	FTG rates	Cross-classification	Regression	Time series	IO	Matrix estimation	Linear	Non-linear
F & C	4	3	1		2			2	1	3	1		1	1	1		2	1
M	17	12	4	1	12	2	8	3	9	7	4	2	5		2	1	11	
S	18	3	14	1	10		6	4	3	4			7		6	2	3	1
Total	39	18	19	2	24	2	14	9	13	14	5	2	13	1	9	3	16	2

Note: F denotes Facility specific applications; C stands for Corridor, M for metropolitan, and S for State.

Copyright National Academy of Sciences. All rights reserved.

Copyright National Academy of Sciences. All rights reserved.

Table 72. Summary of international modeling applications.

Models	Dependent variables	Independent variables	Aggregation	Geography	Modeling technique	Structure	Data Sources
Øresund Traffic Forecast Model - Denmark	C&V	GDP, current trips	A	C	Regression	N	Trip survey, national statistics
Fehmarnbelt Model - Denmark	C&V	GDP, employment, population	A	C	Regression	L	Trip survey, national statistics
TREMOVE - Europe	C&V	Production, consumption, import, export, investment, public expenditures, value density	A	EU	General equilibrium	N	National statistical data on traffic, weight-to-vehicle conversion factors
STREAMS, SCENES - Europe	C	Production, consumption, import, export, investment, public expenditures, value density	A	EU	Multi-regional Input Output (MRIO)	N	IO National tables (Eurostat)
ASTRA - Europe	C	Production, consumption, import, export, investment, public	A	EU	IO, system dynamics	N	IO National tables (Eurostat)
TRANS-TOOLS - Europe	V	GDP per sector	A	EU	Regression	L	Basematrix, traffic counts, Eurostat and EC growth projections.
EUFRANET (rail) - Europe	C	Employment, GVA, trade imports and exports	A	EU	Regression	L	Shippers survey
CGEUROPE - Europe	C	Production, consumption, import, export, investment, public material expenditures, value density	A	EU	Spatial Computable General Equilibrium (SCGE)	N	Harmonized National IO tables
SASI - Europe	C	Production, consumption, import, export, investment, public material expenditures, value density	A	EU	Regional production functions	N	Harmonized National IO tables
CROW Trip rate Parameters - Netherlands	V	Land use, number of employees	D	F	Regression	L	Company surveys
Hamburg Freight model- Germany	V	Land use, number of employees	D	M	Regression	L	Company surveys
FRETURB - France	V	Land use, number of employees	D	M	Regression, tour generation	L	Company surveys
Tokyo urban freight model - Japan	V	Land use, number of employees	D	M	Regression, tour generation	N	Company surveys
SAMGODS - Sweden	C	GDP, distances, commodity price, domestic public sector demand	A	N	MRIO	L	National account data (IO) and foreign trade data, regional economic aggregates
SMILE - Netherlands	C	Production, consumption, import, export, investment, public expenditures, value density	A	N	MRIO, added trip gen through warehouses	N	National account data (make/use) and foreign trade data, regional economic aggregates

(continued on next page)

Table 72. (Continued).

Models	Dependent variables	Independent variables	Aggregation	Geography	Modeling technique	Structure	Data Sources
EUNET2.0 - UK	C	Production, consumption, import, export, investment, public expenditures, value density	A	N	MRIO, added trip gen through warehouses	N	National account data (IO) and foreign trade data, regional economic aggregates.
WFTM - Belgium	C	Production, consumption, import, export, investment, public expenditures, value density	A	N	MRIO, elastic trade coefficients	L	National account data (IO) and foreign trade data, regional economic aggregates
SISD - Italy	C	Production, consumption, import, export, investment, public material expenditures, value density	A	N	MRIO, elastic trade coefficients	L	National account data (IO) and foreign trade data, regional survey data, regional economic aggregates
MOBILEC - Netherlands	C	Production, consumption, import, export, investment, public material expenditures, value density	A	N	Regional production functions	N	National account data (IO) and foreign trade data, regional survey data, regional economic aggregates
RAEM - Netherlands	C	Production, consumption, import, export, investment, public material expenditures, value density	A	N	SCGE	N	National account data (IO) and foreign trade data, regional survey data, regional economic aggregates
NEMO/PINGO - Norway	C	Production, consumption, import, export, investment, public material expenditures, value density	A	N	SCGE	N	National account data (IO) and foreign trade data, regional survey data, regional economic aggregates
INTERLOG - Germany	C&V	Regional and sectoral economic aggregates	D	N	Regression, Monte Carlo simulation, tour structures	N	National and regional economic aggregates
Modelo Nacional de Transporte de Carga - Colombia	C	Production, GDP by department, population	A	N	Four step, regression models	N	Population, economic statistics, traffic counts, origin-destination surveys

Copyright National Academy of Sciences. All rights reserved.

Table 73. International modeling applications by level of geography.

Geography	Number of cases	Dependent Variables			Independent Variables				Aggregation Level		Modeling Technique				Structure	
		Vehicle trip	Commodity flow	V&C Combination	Employment	Land use variables	Population	Others	Aggregate	Disaggregate	Production functions	Equilibrium	Regression	IO	Linear	Non-linear
F	1	1			1	1				1			1		1	
M	5	3		2	4	3	1	1	2	3			5		3	2
N	10		9	1			1	9	9	1	1	2	2	5	3	7
EU	7	1	5	1	1			9	7		1	2	2	2	2	5
Total	23	5	14	4	6	4	2	19	18	5	2	4	10	7	9	14

Note: F denotes Facility specific applications; C stands for Corridor, M for metropolitan, N for National, and EU for Europe.

Report 298). A unique feature of these applications is that they require relatively accurate estimates of FTG for a wide range of land use types to determine user fees, traffic mitigation measures, among other things. These analyses are usually made using the Institute of Transportation Engineers (ITE) *Trip Generation Manual* (2008) and Chapter 5 of the *Quick Response Freight Manual.* Both the ITE Manual and the *Quick Response Freight Manual* describe data requirements and procedures for conducting these analyses. The following sections provide a summary of these important references.

ITE Trip Generation Methods

This section discusses two key publications produced by the ITE: the ITE *Trip Generation Manual* and the ITE *Trip Generation Handbook.* Because of their importance, some level of detail is provided in this review. The ITE *Trip Generation Manual,* 8th Edition (2008) contains FTG data for 162 land uses under ten major land use categories (i.e., Port and Terminal, Industrial/Agricultural, Residential, Lodging, Recreational, Institutional, Medical, Office, Retail, and Services) for several time analysis periods (e.g., weekdays and weekends).

For each land use, the ITE Manual provides the weighted average trip rate, a regression equation (if there are sufficient data for estimation), and the data plot showing the observations. The independent variable is typically a measurable and predictable unit describing the study site that can be used to predict the number of trips or trip ends. Typical independent variables include the number of employees, gross floor area, number of vehicles, etc. Reported statistics include average trip rate, standard deviation, and the statistics for regression analysis.

The trip rates listed in the ITE Manual are for all vehicle-trips. For some of the land use types, the ITE Manual provides an estimated percentage of truck trips among all vehicle-trips. Table 74 provides a summary of these land use types, and their share of truck trips. The techniques described in the ITE Manual could also be used for freight traffic. How to select independent variables and trip generation methods is described in the ITE *Trip Generation Handbook,* 2nd Edition (2004).

The ITE *Trip Generation Handbook,* 2nd Edition (2004) provides guidelines for selecting independent variables, time period of analysis, and estimation methods to use. Although these guidelines are developed for all vehicle types, they could be applied to FTG. However caution should be applied when using them. The ITE Handbook also recommends the use of independent variables that: (1) appear to be a "cause" for the variation in trip ends generated by land use; (2) could be obtained through primary measurement and not derived from secondary data; (3) produce a rate/equation that best fits the data; and (4) are related to the land use type and not solely to the individual site characteristics of the site tenants. In terms of preferred time period of analysis, the ITE Handbook suggests ". . . the time period in which the combination of site-generated traffic and adjacent street traffic is at its maximum." To select the most appropriate estimation methods among the graphic plot (local data collection), weighted average rate, and regression equation, a detailed step-by-step guideline is provided. The document also suggests guidelines and procedures for how to: conduct a trip generation study to obtain local generation rate; consider pass-by, primary, and diverted linked trips; estimate trip generation for general land uses; and conduct trip generation for multi-use development.

Copyright National Academy of Sciences. All rights reserved.

Table 74. Land use classifications with truck traffic in trip generation.

Land Use Code	Land Use Catergory	Truck trips
010	Waterport/Marine Terminal	38% of weekday traffic at container terminals
		60% of weekday traffic at break-bulk terminals
021	Commercial Airport	Less than 1% of weekday and weekend traffic
022	General Aviation Airport	3-5% of weekday traffic
030	Truck Terminal	70% of site-generated driveway volume at an intermodal
		34% of driveway volume at truck terminal located on
130	Industrial Park	1-22% of weekday traffic. Average was approx. 8%
150	Warehousing	20% of weekday traffic at one of the sites surveyed
151	Mini-Warehouse	2-15% of weekday traffic at sites surveyed
152	High-Cube Warehouse	9-29% of peak hour traffic. Additional data provided
254	Assisted Living	% of trucks in different time periods provided in a table
731	State Motor Vehicles Department	0.44% of the weekday traffic (range of 0.12% to 0.85%)
732	United States Post Office	1.2% of the weekday traffic
760	Research and Development Center	1.84% of weekday traffic (range of 0.4% to 4.0%)
813	Free-Standing Discount Superstore	% of trucks in different time periods provided in a table
815	Free-Standing Discount Store	2% of weekday traffic
816	Hardware/Paint Store	1-3% of weekday traffic. Average approximately 2%.
860	Wholesale Market	30% of total traffic at the site
890	Furniture Store	1-13% of weekday traffic. Average approximately 5%.
931	Quality Restaurant	1-4% of weekday traffic. Average approximately 1.6%.

Appendix A of the ITE Handbook (2004) specifically discusses FTG. The discussion, however, is only informational and ". . . provides no recommended practices, procedures, or guidelines." The Appendix defines three categories of uses of FTG: (1) traffic operations that are directly affected by the presence of trucks in the traffic stream; (2) design considerations that need to be addressed with the aid of truck traffic data including both pavement design and geometric design of the street or roadway; and (3) public and political concerns about the traffic impacts of developments, that are often debated in public hearings/meetings and the press. This Appendix includes 23 references on previous research on truck trip generation, some of which contains specific trip generation data. However, the Appendix explicitly states that "many of the existing data sources are quite dated . . ." and "many of the studies on truck trip generation have used very general categories of land use." Therefore these existing FTG rates data should be used with caution. The Appendix also identifies the inconsistencies in existing FTG studies in terms of the definition of trucks and truck trips, and states that: "the independent variables that provide the greatest statistical reliability for 'all-vehicle' trip generation may not be the most appropriate for estimating truck trip generation." Therefore, the independent variables need to be enhanced or refined, so that the most appropriate variables (predictors) can be identified and used for FTG.

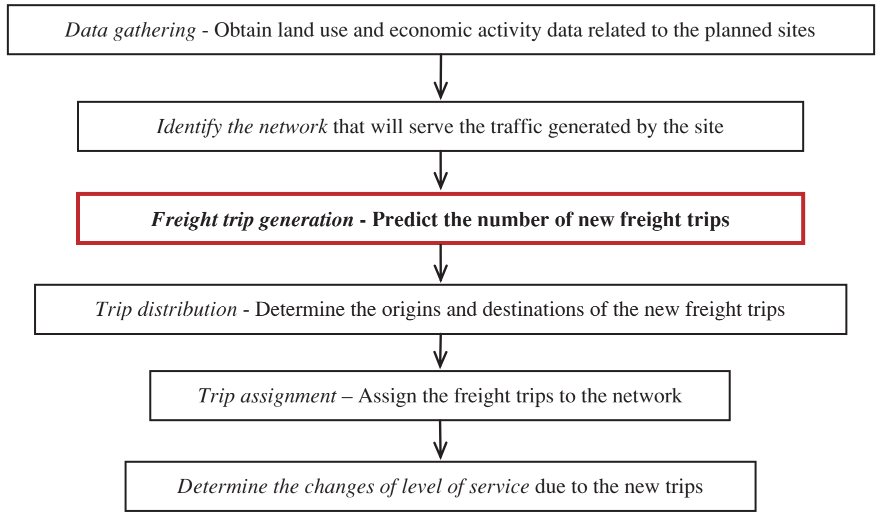
Quick Response Freight Manual

Chapter 5 in the *Quick Response Freight Manual* describes specific data requirements and procedures for conducting site analysis related to freight. The *Quick Response Freight Manual* was developed for the Travel Model Improvement Program by the FHWA of the United States Department of Transportation (USDOT). The *Quick Response Freight Manual* summarizes the purpose of freight-related site analysis is ". . . to estimate, within an acceptable level of accuracy, the number of new commercial trips generated by a new or planned facility and determine whether or not the existing network of primary highways, local roads, municipal streets and other transportation facilities can sufficiently handle the projected traffic demands." The report makes a distinction between site analysis for existing and planned facilities. The recommended process for site analysis is shown in Figure 18.

Freight trip generation (FTG) is thus the third step in this process. In terms of data gathering, the report specifies that data can be obtained from various sources including the developer, designer, owner, or contractor, or the local/municipal/city engineer's office that issues construction permits and approves plans and specifications. In summary, the following data items may need to be collected:

- Company/owner name and address.
- Type of facility to be operated on site (e.g., retail, industrial, manufacturing, warehousing, etc.) and the activities involved.
- Size of the facility in terms of land area, floor area, number of employees, etc.
- Type of commodities, products or services produced and consumed.
- Anticipated volume of shipments and receipts expressed in either weight, volume, dollar value or other freight units.

Copyright National Academy of Sciences. All rights reserved.



Source: Cambridge Systematics Inc. (1996)

Figure 18. Recommended process for site analysis.

- Type of vehicles or carriers to be used for transportation as well as the company or agency that will be responsible for shipping.
- Locations of markets for commodities and services produced (e.g., local, intercity, out-of-state, international).
- Locations of markets for materials, commodities or services used (e.g., local, intercity, out-of-state, international).
- Locations of intermediate facilities (i.e., warehouses, consolidation points) that will serve the new facility.
- Schedule of shipping operations.

The report indicates that detailed data—such as the type and volume of commodities used and produced, the locations of origins and destinations of the shipments, and the schedules—need to be obtained by conducting interviews and surveys with the appropriate individuals.

In identifying the network of transportation facilities, the *Quick Response Freight Manual* suggests that all existing physical and operational characteristics of network facilities have to be described according to size, capacity, traffic volumes, geometry, speed limits and any other restrictions on use or access (e.g., truck size and weight limits). The characteristics of the traffic that the facilities serve need to be obtained as well, because they may also be relevant to the site analysis. The sources of transportation network and traffic data include the Design and Traffic Divisions of City or Local Governments, DOTs, MPOs, and other planning agencies.

The *Quick Response Freight Manual* highlights that for site analysis, more accurate and detailed FTG estimation is required. Two FTG methods are recommended, including: (1) site-specific trip generation rates; and (2) regression equations, although other methods that can significantly improve the forecasts of the demands for freight transportation due to the new facility may also be used. It is worthy of mention that, in addition to the total number of new trips, the analyst may also be interested in the distribution of these trips on a given day, week, or even month. These temporal characteristics are important in determining the impacts of the new traffic on the peaking patterns around the site. In summary, to conduct the estimation, the following factors need to be considered:

- Land use.
- The number of employees and households.
- The total floor/building area, or total land area of the facility.
- Type, weight and volume of commodities produced and consumed.
- Commodity classifications.
- The sizes and capacities of vehicles.
- Modes and carriers available.
- The frequency and scheduling of shipments.
- The storage and handling operations.
- Other factors that influence the total demand for freight transportation by the facility.

The report recommends that the analyst explore these and the many other types of relationships between anticipated freight traffic and the site/facility characteristics. Appendix D of the report contains tables that summarize the detailed daily trip generation rates for each location, land use type, and truck classification. The trip generation rates are provided for the following land use types for different types of vehicles (the numbers in the parentheses are the SIC codes):

- Agriculture, Mining and Construction (1–19).
- Manufacturing, Transportation/Communications/Utilities, and Wholesale Trade (20–51).

Copyright National Academy of Sciences. All rights reserved.

Table 75. Data collection for special trip generators.

Special Trip Generators	Data Collection Requirements	Data Sources
Highway	Average daily freight activity per site by truck classification, for both inbound and outbound	Fleet manager of the planned facility
Water	Loadings and unloading in twenty foot equivalent units (TEUs), or forty foot equivalent units (FEUs)	Port Facilities Inventory U.S. Waterborne Exports and Outbound Intransit Shipments and the converse for imports Tonnage for Selected United States Ports
Rail	Origins and destinations, number of cars, tons, length of haul, Participa-ting railroads and interchange locations	Carload Waybill Sample
Air	Freight express and mail traffic carried byairport and airline; operational information on Air and Expedited Motor Carriers Conferen-ce members by airport	The Airport Activity Statistics of Certificated Route Air Carriers; The Air and Expedited Motor Carriers Network Guide and the Express Carriers Association Service Directory (produced by the Film, Air and Package Carriers Conference)

Source: Cambridge Systematics Inc. (1996)

- Retail Trade (52–59).
- Offices and Services (60–88).
- Unclassified (89).

For each of the land uses, FTG rates are given in terms of employees, 1,000's of square feet of office space, and acreage. In the case of special trip generators such as intermodal terminals, trip generation estimates can be obtained through direct contacts with a limited number of firms and with specific questions. Actual trip generation data can generally be obtained through direct contacts, observation, or surveys. If not, the report suggests the use of the default values in Appendix D of the report. The report describes the types of data that may be sought for different modes including highway, water, rail, and air, as depicted in Table 75. The specialized database section in Appendix K-4 of the report also includes data sources for other modes including pipelines, coal movements, military transportation, Mexican and Canadian trade, imports and exports, and other topics.

Identification of Key Variables

The identification of the variables that influence FG/FTG must take into account the inherent differences between the generation of freight, and the generation of freight vehicle trips as well as the interplay between the level of detail in the definition of the land use classes, and the level of aggregation of the FG/FTG modeling effort. These aspects are discussed in this section, in connection with the identification of the key variables.

As discussed throughout this document, and specifically in Chapter Three, from the conceptual and practical points of view it is best to explicitly consider the process of FG, and FTG. This reflects the fact that FG and FTG are determined by fundamentally different processes. In the case of FG, the amount of cargo generated is a reflection of a production process in which a set of intermediate inputs, labor, and capital interact to create a set of economic outputs. The function of land use is, in most cases, to provide the physical space and conditions to make such production process feasible. The exceptions are specific economic activities, e.g., agriculture, in which land could definitively be considered an economic input. As a result, the ability of land use variables to explain and predict FG and FTG depends on how well a land use class could act as a proxy for the kind and intensity of the economic activity being performed at the site.

In contrast, FTG is determined by the minimization of the total logistic costs associated with the transportation of the FG. In essence, once the output of the production process has been determined, businesses determine the best combination of shipment sizes and delivery frequency to transport the freight generated at the site. These decisions determine the FTG. As a result, FTG is a reflection of the way the industry arranges itself to transport the FG.

The second aspect of importance is related to the interactions between the level of detail in land use, and the level of aggregation used in the models. It is useful to classify the different possibilities as a function of the level of detail used to define the land use classes, and the level of detail used in the FG/FTG modeling process. In a simplified fashion, one could define the following classification:

- Land use level of detail:
  - Specific, i.e., when the land use class maps directly into a well-defined industry sector.

Copyright National Academy of Sciences. All rights reserved.

  - General, i.e., when the land use class includes multiple industry sectors.
- Level of aggregation of the FG/FTG modeling process:
  - Disaggregated, i.e., when the models focus on the estimation of FG/FTG for a specific establishment.
  - Aggregated, i.e., when the FG/FTG models focus on the generation of conglomerate of businesses.

It should also be said that, although there are multiple gradations of these groups, using such a simplified classification serves the purpose of illustrating the interplay between level of detail in land use, and level of aggregation in the modeling process. The key combinations are shown in Table 76. It is important to highlight that Table 76 does not make a distinction between the estimation of a model and its application, either for engineering or planning applications. It is also understood that the data required to estimate the models has to be consistent with the level of detail in land use, and the level of aggregation of the FG/FTG modeling effort. In other words approaches based on disaggregate modeling require disaggregate data as an input. Similarly, once a set of land use classes has been selected and used for model estimation, any ensuing applications will necessitate a comparable set of inputs.

As shown in Table 76, four possibilities are defined. As indicated in the remarks in each cell, the different combinations exhibit radically different levels of performance.

Specific Land Use Classes Combined with Disaggregate FG/FTG Modeling

This case corresponds to the situation in which a relatively narrowly defined land use class, e.g., food retail, is used as the mechanism to group a set of establishments for modeling purposes. During the estimation process, disaggregate FG/FTG models are estimated with the land use variables, e.g., square footage, corresponding to the establishments.

The limited experience with these types of approaches indicates that using land use variables for FG/FTG modeling at specific land use classes could perform as well as economic variables such as employment. This is certainly the case when variables such as square footage are used to explain and predict FTG (Bartlett and Newton 1982; Tadi and Balbach 1994). The reason is related to the fact that—at the establishment level and for the same type of economic activity—variables such as square footage may indeed be able to capture the effects of business size on FG/FTG. In essence, *for the same line of business,* an establishment with a larger built area may be expected to produce more FTG than a smaller one. The combined effect of a narrowly defined land use class, together with establishment level land use data, and disaggregate FG/FTG modeling, is expected to provide sufficient results.

General Land Use Classes Combined with Disaggregate FG/FTG Modeling

In this scenario, a broadly defined land use class is used to group a set of business activities under a heading such as "retail," "commercial," and others like them. As a result, these general land use classes tend to include rather disparate mixes of economic activities, with diverging FG/FTG patterns. The net impact is that the ability of land use variables, e.g., built area, to explain FG/FTG is reduced by the internal heterogeneity of the FG/FTG patterns inside the land use class. The chief implication is that the larger the degree of heterogeneity, the less capable land use variables will be to explain FG/FTG.

Specific Land Use Classes Combined with Aggregate FG/FTG Modeling

In this scenario, a narrowly defined land use class (e.g., food stores, retail) is used in combination with aggregate modeling intended to produce FG/FTG for conglomerations of business establishments, e.g., at the zonal level. The accuracy of these approaches depends on two different factors. The first relates to how well the independent variables explain FG/FTG. The

Table 76. Scenarios of land use detail and level of aggregation in FG/FTG modeling.

		Level of Aggregation in FG/FTG Modeling Process	
		Disaggregated	Aggregated
Level of Detail in Land Use Class	Specific	Land use variables expected to work relatively well in explaining FG/FTG	Could work well as long as the explanatory variables and aggregation procedures used are appropriate
	General	The ability of these models to explain FG/FTG diminishes with the heterogeneity of the industry sectors included in the land use class, and the explanatory power of land use variables	The ability of these models to provide accurate estimates of FG/FTG could be hampered by both the validity of the aggregation procedure and the broadly defined land use classes

Copyright National Academy of Sciences. All rights reserved.

second is much less obvious, as it relates to the ability of the model to capture the aggregate patterns of FG/FTG.

In essence, a good aggregate model is one that is consistent with the disaggregate behavior of those users the model intends to represent, and which, as a result, is able to accurately predict the aggregate FG/FTG. As discussed in this final report, there is only one way to aggregate results for a given disaggregate model. If the specification used in the aggregate model is consistent with the correct form of aggregation, the aggregate model would have a better chance of making accurate predictions. Otherwise, it will lead to erroneous results. This is a major concern because it is routinely assumed that FTG rates are constant, when in fact, the sparse data show that a significant amount of industry sectors exhibit constant FTG, which leads to FTG rates that decline with business size. As a result, estimating the aggregate FTG as the multiplication of the total employment by a constant FTG rate is extremely problematic if the underlying FTG is constant at the establishment level. For instance, if the business in a given transportation analysis zone has a constant FTG (e.g., five truck trips per establishment per day) the correct way to estimate the total FTG is to multiply the number of businesses by the unit FTG of five truck trips/establishment. In this context, attempting to estimate the total FTG by multiplying the total employment times an assumed FTG rate per employee will translate into large estimation errors. The issue here is that the constant FTG translates into FTG rates that decrease with business size, which are not captured by the constant FTG rate.

General Land Use Classes Combined with Aggregate FG/FTG Modeling

This scenario considers the use of a general land use class, e.g., "commercial," that groups various industry sectors, in combination with an aggregate FG/FTG modeling effort. As may be expected, the effectiveness of these modeling approaches is hampered by both the heterogeneity of the FG/FTG patterns included in the land use class, and the aggregation issues discussed in the previous section. As a result, these modeling applications are expected to exhibit the lowest performance in terms of accuracy and conceptual validity.

The chief implications of this discussion are that:

- FG is likely to be explained with the use of economic variables, e.g., employment level, as they represent the input factors of the corresponding economic processes.
- FTG is determined by total logistic cost considerations. Since the corresponding explanatory variables are not readily available, the estimation of FTG models is likely to require the use of proxy variables such as land use type.
- The performance of land use variables depends on how they are defined and integrated into the FG/FTG modeling process.
- Great care must be taken to ensure that the aggregation procedures used to estimate FG/FTG at an aggregate level are adequate. Not doing so may lead to large estimation errors.

Criteria to Determine Best Practices

The analyses conducted by the team indicate that the identification of best practices has to take into account three separate aspects:

- Level of detail used in the definition of the land use classes used.
- Level of aggregation of the FG/FTG modeling effort.
- Modeling technique used to actually estimate the FG/FTG model.

It is important to discuss these separately because the ability of a modeling technique, e.g., regression analysis, to produce good results depends on both level of detail in land use and the level of aggregation of the model. The discussion takes place in two parts. The first focuses on the first two aspects, and the second on the third. The expected performance of the various combinations is assessed according to the following evaluation criteria:

- Data requirements for both model estimation and calibration.
- Conceptual validity of the approach, i.e., the consistency of the approach with respect to the reality being modeled.
- Practicality, i.e., how easy it is to apply the model in an application context.
- Relevancy to the application context.
- Expected accuracy of the approach, i.e., how likely it is to produce accurate results.

Level of Detail in Definition of Land Use Classes vs. Level of Aggregation in FG/FTG Model

Table 77 shows the team's assessment of the performance of the various possibilities of level of detail and level of aggregation, according to the various evaluation criteria. In terms of conceptual validity and accuracy, there is no doubt that disaggregate models are better than their aggregate counterparts. This is an obvious consequence of their enhanced ability to capture the connections between FG/FTG and the establishment attributes. Disaggregate models also require less data than aggregate models. It suffices to say that most FG/FTG disaggregate models are estimated with 20–50 observations, while the estimation of aggregate models typically requires the kind of data collected by origin-destination surveys.

However, disaggregate models require disaggregate forecasts, which may strain the forecasting ability of most transpor-

Copyright National Academy of Sciences. All rights reserved.

Table 77. Summary evaluation of combinations of land use detail and level of aggregation.

Model features:			Evaluation criteria:					
							Appropriateness for:	
Level of detail on land use class	Level of aggregation of modeling effort	Type of independent variable used	Conceptual validity	Accuracy	Data requirements	Practicality	Engineering applications	Planning applications
Specific	Disaggregate	Economic	(+++)	(+++)	(++)	(++)	(+++)	(+++)
		Land use	(+++)	(+++)	(++)	(++)	(+++)	(+++)
Specific	Aggregate	Economic	(++)	(++)	(– – –)	(+++)	(– – –)	(++)
		Land use	(–)	(++)	(– – –)	(+++)	(– – –)	(++)
General	Disaggregate	Economic	(–)	(– –)	(+++)	(++)	(++)	(– –)
		Land use	(– –)	(– –)	(+++)	(++)	(++)	(– –)
General	Aggregate	Economic	(– –)	(– – –)	(– –)	(++)	(– –)	(– –)
		Land use	(– – –)	(– – –)	(– –)	(++)	(– –)	(– –)

Note: Better (+++) to Worse (---)

tation demand models. This may require the use of assumptions to allow for the extrapolation based on the observed conditions for the base year. For these reasons, it is fair to conclude that disaggregate models are slightly less practical than aggregate ones. In terms of appropriateness for engineering and planning applications, here again disaggregate models are the best alternative. As indicated in the table, while disaggregate models could meet the needs of both types of applications, aggregate models, because of their nature, could only deal with planning applications.

The picture that emerges is that disaggregate models do provide the best overall alternative, though there are issues—such as the ones concerning the need for disaggregate forecasts—that need to be dealt with. In spite of this limitation, the team is confident that disaggregate FG/FTG models do represent the most promising approach, particularly if the CFS micro-data are used in their estimation.

Modeling Techniques

The second aspect of importance is the modeling technique used to estimate the FG/FTG model. Although there are a number of special use (mostly facility specific) techniques that could be used (e.g., time series, artificial neural networks), the main emphasis of this discussion is on the techniques of wider applicability. More specifically, the discussion considers the cases shown in Table 78.

As shown, the alternative modeling possibilities have been placed in the larger context of the modeling platforms in use for freight demand modeling (i.e., vehicle-trip-based, commodity-based) which makes it easier to connect FG/FTG analyses to advantages and disadvantages of these platforms. As discussed elsewhere (Ogden 1992; Holguín-Veras and Thorson 2000), the use of vehicle-trip or commodity-based models has a number of implications, summarized in Table 79. As the reader can see, there is consistency between the findings discussed in the report and the pros and cons for the modeling platforms previously identified in the literature.

It is important to mention that since the modeling techniques, as implied in Table 78, can be applied to either modeling platform, they could be discussed in general terms. (The exception is IO analysis that cannot be applied in vehicle-trip models.) This discussion is presented in the following sections.

FG/FTG (Constant) Rates

This technique is, without any doubt, the simplest and most widely used of all. The reasons are obvious, as the FG/FTG

Table 78. Cases considered.

Modeling technique	Modeling platform	
	Vehicle-trip based	Commodity based
Rates	FTG rates	FG rates
Regression	FTG regression models	FG regression models
Input-Output	Not applicable	IO models

Copyright National Academy of Sciences. All rights reserved.

Table 79. Implications of alternative modeling platforms.

Impacts	Modeling platform	
	Vehicle-trip based	Commodity based
Advantages	Independent variable (vehicle-trip) is easy to measure	Does consider the economic characteristics of the cargo
	It includes loaded and empty trips	Resembles the real life process
Disadvantages	Does not consider the economic characteristics of the cargo	Requires surveys to estimate commodity flows
	Poor connection to the underlying economics	Requires complementary models to estimate loaded and empty trips
	Cannot be used for mode choice	

rates are computed directly from the data, typically as the summation of the vehicle trips (FTG) or tons (FG) produced and/or attracted by a sample of establishments, divided by the summation of the values of a suitable independent variable (e.g., employment, gross area). Although in almost all cases, vehicle trips are used, there is no reason preventing the use of rates to estimate commodity generation. Graphically, the rate is the slope of the line through the origin in Figure 19.

Although pragmatic and simple to use, the use of a constant FTG rate has a number of problems:

- It forces the estimated FTG to pass through the origin, without statistically testing the validity of such assumption (as discussed, for instance, 85% of the industry sectors in NYC do not meet this assumption).
- As a consequence of the above, using a constant FTG rate in industry sectors that do not meet the assumption of direct proportionality between FTG and the independent variable used, will underestimate the FTG for businesses smaller than average, and will overestimate the FTG for those larger than average; as shown in Figure 13.

It is not clear how well a constant rate would perform in modeling FG as no such applications have been reported in the literature. However, the team would expect that since the problems that impact their application for FTG modeling (e.g., indivisibility of vehicle trips, the role of shipment size) do not impact FG, a constant FG rate could work reasonably well.

FG/FTG Regression Models

In these techniques, a statistical relation between a dependent and a set of independent variables is empirically estab-

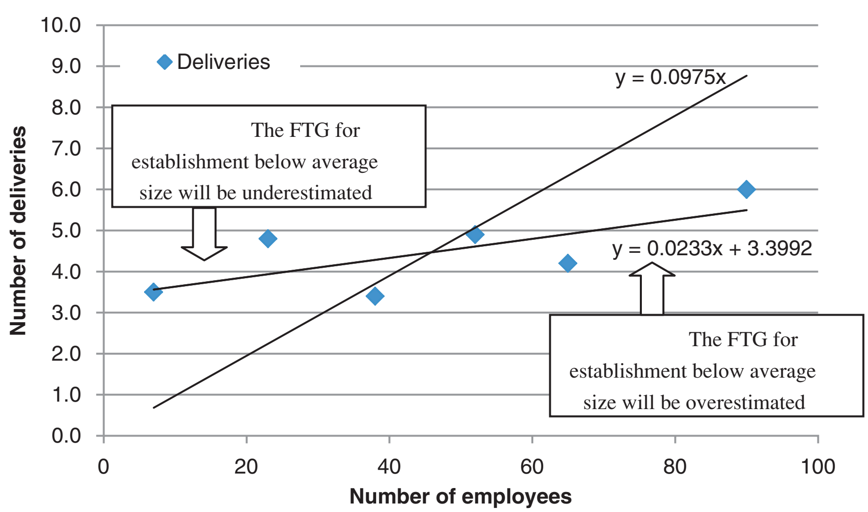


Figure 19. Constant FTG rate model vs. regression model with intercept.

Copyright National Academy of Sciences. All rights reserved.

Table 80. Summary evaluation of modeling techniques.

Model features:		Evaluation criteria:					
Modeling technique	Type of model	Conceptual validity	Accuracy	Data requirements	Practicality	Appropriateness for: Engineering applications	Appropriateness for: Planning applications
Constant Rates	FG	(+)	(+)	(+++)	(+++)	(-)	(++)
	FTG	(--)	(---)	(+++)	(+++)	(--)	(--)
Regression	FG	(+++)	(+++)	(+)	(++)	(++)	(+++)
	FTG	(+++)	(++)	(+)	(++)	(++)	(+++)
Input-Output	FG	(+++)	(++)	(--)	(--)	(--)	(++)
	FTG	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.

Note: Better (+++) to Worse (---)

lished. Of great significance is that the statistical significance of the independent variables is assessed, and that, as a result, the final models only contain the independent variables that play a meaningful role in explaining the phenomenon under study. These techniques are extremely flexible, and are able to estimate linear and nonlinear models, with or without intercept, and under several assumptions of correlation structures. Regression models do tend to require more data than FG/FTG rates; while most analysts would feel comfortable estimating simple regression models with about 30 observations, FG/FTG rates could be estimated with a handful of data points (and even with only one). With such a combination of flexibility, and statistical rigor in the inclusion of only the independent variables that do play a role, it is hard to argue against the validity of FG/FTG regression models.

Input-Output Models

These techniques are based on economic tabulations of the cost of inputs (e.g., steel, energy) that are required to produce a unit of economic output (e.g., a certain number of cars) at the national or regional level. Once the economic output, or final demand, is set, the IO matrix can be used to estimate the corresponding inputs, also referred to as intermediate demands. In the case of multi-region IO applications, where the origin of the inputs must also be estimated, these are accomplished with the assistance of spatial interaction models. The commodity flows are estimated from the economic flows using suitable values of cargo, and reversing the origins and destinations (the commodity flows run counter to the economic flows). For reviews of freight demand IO modeling the reader is referred elsewhere (Kanafani 1983; de la Barra 1989).

The use of IO models is generally considered to be a solid technique that is grounded in well-established economic theory. However, there are a number of observations that should be made:

- The set of parameters that link the output to the corresponding inputs, i.e., the technical coefficient matrix, is usually estimated using national or regional accounting techniques. For that reason, their validity is doubtful for smaller geographic units such as transportation analysis zones (Bureau of Economic Analysis 2007).
- The fixed nature of the technical coefficients (variable coefficients have been found extremely difficult to estimate) does not allow IO models to consider structural changes in the economy that may change the proportions in which the inputs are consumed.

For these, and other reasons the use of IO models has been phased out in Europe in favor of general equilibrium models, which are able to capture the connections between economic activities, regional patterns of commerce, and transportation accessibility. These models estimate FG as an endogenous variable, i.e., as an output of the model, and have been successfully applied at the regional and European levels.

Taken together, the team's assessment of the various modeling techniques can be summarized in Table 80. As shown in the table, constant rates, though practical and not requiring much data, are of questionable validity and likely inaccurate, because of the embedded assumption of proportionality between FTG and business size. Regression models, particularly at the disaggregate level, do seem to represent the best technique available for both engineering and planning applications. IO modeling, though conceptually solid, cannot address the needs of engineering applications that require estimates of FG/FTG.

Copyright National Academy of Sciences. All rights reserved.

APPENDIX F

Review of the Literature on Data and Surveys

This chapter summarizes the current literature on data collection techniques and data sources. The review focuses on two main topics:

- **Data collection techniques.** This section reviews surveys and other data collection techniques that are relevant to the study of FG/FTG. It includes the various survey techniques and newly emergent technologies that can be used for FTG data collection, such as Global Positioning Systems (GPS).
- **Data Sources.** This section reviews data sources that are currently available for FG/FTG analysis and modeling. It describes primary data sources that are directly related to freight activities, and secondary data sources, such as GPS data and other Intelligent Transportation Systems (ITS) related data.

Data Collection Techniques

Freight data collection techniques are intended to address multiple needs. Data of various kinds must collected, including: (1) types and amount of commodities shipped; (2) modes of conveyance utilized; (3) origins and destinations; (4) shipment and terminal travel times; (5) loading and berthing requirements; (6) daily and hourly variations in shipments; and (7) frequency of shipments. The number, type, and weight of commodities carried in relation to the nature and magnitude of the activities served are important in developing FG/FTG models, and in accessing the need for roadway and access improvements. Data needs and collection is probably "the biggest single issue" challenging the development of freight modeling (Kuzmyak 2008, 38), and has been the focus of several NCHRP studies. For example, the data needs, sources, and collection techniques for FTG are the main focus of *NCHRP Synthesis 298: Truck Trip Generation Data* (Fischer and Han 2001). *NCHRP Synthesis 384: Forecasting Metropolitan Commercial and Freight Travel* also discusses the data issues of freight modeling, and identifies cost and confidentiality as the two most challenging issues. Under the freight demand modeling framework that includes FTG as a subcomponent, Holguin-Veras et al. (2001) and Holguín-Veras et al. (2010) investigated the freight data issues in a broader sense. This section summarizes previous efforts, and current data collection practice.

Data Needs for FTG

Similar to other modeling frameworks in transportation, the accuracy, resolution, and coverage of relevant data elements are important for FG analysis and modeling. Tables 1 and 2 obtained from Holguín-Veras et al. (2010) provide a framework for FTG data collection, analysis and modeling. The type, location, and intensity of various activities are a basic input to the data category shown in Table 81. A description of the role and importance for each of the various data classes is provided in Holguín-Veras et al. (2010). Table 82 presents a summary of data needs pertinent to FG and FTG, as adopted from Holguín-Veras et al. (2010). In the table, "C" stands for models for calibration and "F" stands for models for forecasting purposes.

Review of Data Collection Procedures

Data collection is necessary in order to supplement the data sources currently available. This section describes the key findings from a comprehensive review of freight data collection approaches. As previously discussed, there are key issues involved in freight transportation that affect the efforts of conducting freight transportation surveys, and the different means of collecting data. These key issues are: (1) multiplicity of metrics to define/measure freight; (2) multiplicity of factors to determine freight/freight trip generation, distribution and the other factors that determine demand; (3) multiplicity of economic agents involved; and (4) agents that only have a partial view of the freight system. All of these aspects complicate

Copyright National Academy of Sciences. All rights reserved.

Table 81. Data categories for FTG modeling.

Data class	Items
Freight generation data (amount of commodities, vehicle trips, deliveries)	Production
	Consumption
Delivery tours	Sequence of stops
	Location of deliveries
	Commodity, vehicle-trip OD flows
	Empty trips
Economic characteristics of participating agents	Shippers, warehouses, forwarders
	Carriers
	Receivers
Spatial distribution / Location of participating agents	Shippers, warehouses, forwarders
	Carriers
	Receivers
Network characteristics	Travel times, costs
	Use restrictions
	Capacity
	Traffic volumes
Other economic data	Production functions
	Demand functions
	Input-Output technical coefficients

Source: Holguín-Veras et al. (2010)

Table 82. Data needs for alternative FTG modeling approaches.

Aspect:		Commodity generation models	Input-Output models	Empty trip models	Trip generation models
Information/insight into logistical pattern of flows			C*		
Freight generation data	Production	C	C, F**		C
	Consumption	C	C, F		C
Delivery tours	Sequence				
	Location				
	OD flows		C, F	C, F	
	Empty flows			C	
Economic characteristics of participating agents	Shippers	C, F			C, F
	Carriers	C, F			C, F
	Receivers	C, F			C, F
Spatial distribution / Location of participating agents	Shippers	C, F			
	Carriers	C, F			
	Receivers	C, F			
Network characteristics	Travel times and costs		C, F	C, F	
	Use restrictions		C, F	C, F	
	Capacity		C, F	C, F	
	Traffic volumes				
Other economic data	Production functions				
	Demand functions				
	IO tech. coeffs.		C, F		

*: "C" stands for data for Calibration purpose

**: "F" stands for data for Forecasting purpose

Source: Holguín-Veras et al. (2010)

Copyright National Academy of Sciences. All rights reserved.

tremendously the data collection process. Consequently, it seems clear that a comprehensive approach to freight data collection is best, and to fully describe what happens in the system, a combination of methods may be required.

In general, the different data collection techniques or surveys could be grouped depending on how the sampling frame is defined (i.e., on the basis of the establishments at the origin or the destination of the shipment, the truck traffic, cargo tour). This translates into collection procedures that focus on the origin or destination of the cargo; en-route, as in a truck intercept survey; or along the supply chain the shipment follows. Table 83 presents a summary of the different data collection methodologies depending on their sampling frame. For each frame, the table discusses its application, and the type and collection method generally used, together with the strengths and limitations of each. A clear representation of the level of detail of the data provided by each unit or sampling frame is shown in Table 84. As said before, no single sampling frame can provide a good representation of all the data categories required for freight demand modeling.

As shown in Table 84, these sampling frames do not provide information on freight traffic volumes, which are also needed, for instance, to assess the impact of freight volume on traffic congestion. Collection of freight volumes is mainly performed via Automatic Vehicle Classifier (AVC), or manual counting. Manual counting involves a trained observer collecting vehicle classification counts at a location based on direct observation of vehicles. Alternatively, this can be done using videography, which involves collecting vehicle classification counts using video tape recorders and tallying them manually by observing vehicles on the video with the ability to stop time and review data, if necessary (Beagan et al. 2007). On the other hand, AVC is usually based on techniques such as Weight-In-Motion (WIM), consisting of loop detectors, video cameras, or other types of detectors to automatically classify vehicles and collect freight volume (Sharma et al. 1998). The full installation of

Table 83. Summary of data collection methodologies.

		Description	Application	Type/Collection Methods	Strengths	Weaknesses
Establishment based	Shipper	Provides measures of total sales, market share, materials quantity/cost, modes, production hours, and location data.	Examples include: Commodity Flow Survey, and Annual Survey of Manufacturers.	Self-administered or staff-assisted surveys to agents that ship out the cargoes.	Ability to capture data about the characteristics of the cargo. May be complemented with shipment tracking.	Questionable validity about routes, intermediaries, processing /transfer points, etc. data.
	Receiver	Targets the receivers of the shipments.	Freight/Freight Trip demand generation models.	Self-administered or staff-assisted surveys.	Can provide excellent data about the goods received.	Receivers are unaware of the cargo transportation aspects.
	Carrier	Most widely used approach to collect freight data.	Examples include: Freight Movement Survey and the Highway Carrier Attitude Survey *(17)*	Based on Vehicle Registration samples. Provide vehicle detailed travel information (trip diary forms). Mail-out or CATI surveys *(18)*.	Target population relatively easily defined. Collects good travel patterns data. Vehicle list obtained from Department of Motor Vehicles.	Questionable quality of cargo related data. Mismatch between vehicle registration lists and commercial vehicle population in urban areas *(18)*.
Vehicle based		Individual vehicles as the sampling unit. Collect: origin, destination, trip mileage, travel time, routing, purpose, time of day, commodity, shipment size, truck type, land use, activity at trip end *(16)*	Trip chaining, trip generation, and trip routing *(16)*	Travel diaries. Collect travel diaries for a period of time from a sample of trucks operating in the region.	Useful for understanding internal-internal truck trips in an urban area.	Difficult sampling process. Using vehicle registration samples may produce biased results. Low response rates.
				Assisted by GPS to track the routing patterns inside the study area.	Spatial /temporal movement data could be collected; real time data.	GPS cannot provide the data collected by traditional surveys.
Tour based		Focus on data collection along the supply chain. Individual shipments are tracked long a supply chain.	Use shipments as transportation measurement units. Capture economic relations vital for transport policy.	Longitudinal surveys: individual shipments are tracked along a supply chain.	Provides a comprehensive description of supply chains. Tracks each shipment from shipper to final receiver.	Expensive, budget may condition their success or failure. Requires a very specific survey design *(20)*.
Trip intercept based		Focus on truck /vehicle trips. Collect: routing patterns, OD locations, commodity/ truck type, weights, shipper/receiver/carrier data *(16)*	Freight modeling and planning applications.	Roadside Interviews.	Low costs *(16)*. High response rates. Best statistical control and reliability. Capture trucks entering/ exiting, and passing through the study area.	Limited locations may lead to sampling bias. Potential traffic disruption. Cannot collect tours data. Not effective for internal-internal truck traffic data *(16)*.
Cordon		Collect travel pattern data; origins / destinations at the perimeter of a region; routing patterns; truck/ commodity type; vehicle/ cargo weight; and, shipper / carrier / receiver information.	Freight modeling/planning applications such as: the development of OD freight flow matrices, commodity tonnage distribution to truck classes, empty and through truck factors *(16)*	Roadside postcard survey distribution to be mailed back.	Less likely to disrupt traffic than roadside interviews; requires fewer field personnel.	Response rate is usually lower, which could result in significant nonresponse bias.
				License plate recording /matching with a survey mailed out to be returned *(19)*.	Does not disrupt traffic.	Lag between observation and survey reception may lead to low response rates (and bias) and high recollection errors.

Sources: (Beagan et al., 2007), (Jessup et al., 2004), (Cambridge Systematics, 1996), (Miller et al., 1993), (Rizet et al., 2003)

Copyright National Academy of Sciences. All rights reserved.

Table 84. Sampling frame of different data collection procedures.

■ Excellent level of detail
◘ Good level of detail
▣ Some level of detail
⊡ Low level of detail
□ Only general information

Unit/ Sampling Frame		Freight generation data		Delivery tours				Economic characteristics of participating agents			Spatial distribution / Location of participating agents			Network				Special choice processes			Other economic data		
		Production	Consumption	Sequence	Location	OD flows	Empty flows	Shippers	Carriers	Receivers	Shippers	Carriers	Receivers	Travel times, costs	Use restrictions	Capacity	Traffic volumes	Mode choice	Delivery time	Mode attributes	Production functions	Demand functions	IO tech. coeffs.
Establishment	Shipper	■				◘		■	▣	▣	■	▣	▣					□		⊡			
	Carrier			■	■	■	■	⊡	■	⊡	◘	■	◘	▣	□				▣	▣			
	Receiver		■			◘		▣	▣	■	▣	▣	■					▣		⊡			
Trip intercepts		⊡	⊡	⊡	⊡	◘	▣	⊡	▣	⊡	⊡	▣	⊡	▣	⊡	⊡			⊡	⊡			
Vehicle				■	■	■	■	⊡	■	⊡	◘	■	◘	▣	□				▣				
Tour				■	■	■	■	⊡	■	⊡	◘	■	◘	▣	□				▣				

WIM, however, may be expensive, and is only deployed at limited locations. Other AVC methods include: pneumatic tubes, loop detectors (or other types of magnetic detectors), and video cameras. Pneumatic tubes are easily portable, and need only to be placed across travel lanes to automatically record vehicles. However, the classification accuracy degrades where there is simultaneous crossing of multiple vehicles, such as on high-volume, high-occupancy road segments. Loop detectors involve embedding one or more loops of wire in the pavement, which are very useful under all weather conditions, and used mainly as permanent recorders at locations where counts are required for a longer time duration (Beagan et al. 2007).

Role of Global Positioning Systems (GPS) on Data Collection

In recent times, there has been a great deal of interest in the use of GPS for freight demand modeling. Among other benefits, these data are: very accurate; increasingly common as the number of companies using GPS devices multiplies; and free, as they are the byproduct of vehicle tracking and navigation systems. However, a fundamental limitation that has not been overcome is that GPS cannot collect the key data that traditional surveys provide (e.g., commodity type, shipment size, trip purpose). This presents a number of issues. First, there is no guarantee that the data are representative of the region, as in most cases, the data are biased toward medium and large firms. As a result, the data lack observations for the small companies that transport the bulk of the freight in urban areas. Second, although delivery tours can be estimated from GPS data, shipment sizes and the purpose of the stop are unknown. These are important implications that severely hamper the use of GPS for freight demand modeling.

As a result, the maximum utility of GPS is realized when it is combined with other data collection methods. For example, origin, destination and routing information received from GPS receivers can be used to validate and improve the information provided by truck drivers in manually completed travel diaries. Also, combining GPS truck trip information with Geographic Information System land use data can yield useful information on truck activity characteristics at trip ends (Beagan et al. 2007).

Data Sources

The development of FG/FTG models requires information on freight movements, and the characteristics of the activities that are served. This section discusses the principal freight data sources.

Overview of Data Sources

Several TRB synthesis reports, the Bureau of Transportation Statistics, and a variety of research studies provide useful information for freight data sources:

- *NCHRP Synthesis 298* (2001) summarizes and discusses main data sources for FTG. Data categories include: Compendia of Trip Generation Data, Engineering

Copyright National Academy of Sciences. All rights reserved.

Studies, Special Generator Studies, Port and Intermodal Terminal Data Resources, Vehicle-Based Travel Demand Models, Commodity-Based Travel Demand Models, and Other Critical Data Resources. It also summarizes the data sources presented in each category.

- *NCHRP Synthesis 384* (2008) identifies commodity flow related data resources (e.g., Freight Analysis Framework, Commodity Flow Survey, TRANSEARCH database, Vehicle Inventory and Use Survey, Vehicle Travel Information System, Carload Waybill Sample and WaterBorne Commerce Statistics Database). For urban freight data, *NCHRP Synthesis 384* indicates that vehicle classification counts and OD Survey data may be used.
- The Appendix II in a report for NYMTC by Holguin-Veras et al. (2001) summarizes the main freight data sources (up to year 2001), using a standard format that has been adopted by the Directory of Transportation Data Sources (Bureau of Transportation Statistics 1996). The summary provides the geographical coverage for the data sources, defines the corresponding transportation modes, and identifies the list of attributes in each dataset. The data sources are also classified according to their potential use with information on collecting agency, contact person, means of contact, and other useful information about content, methodology, significant features and/or limitations, distribution media, availability, price and web site. A usefulness-ranking is included, and provided for each data source including the categories: *very useful, useful, marginal* and *specialized.*
- A report by Holguín-Veras et al. (2010) updates the 2001 NYMTC report. The update was presented as notes to the original data sources to avoid confusion, since some sources may have been subject to name changes or were discontinued. In addition to updates for the original sources, Holguín-Veras et al. (2010) documents a description of new data sources or reference material and tools.

Primary Data Sources

There are a large number of primary data sources on freight activity, though the coverage they provide is still lacking. For a comprehensive review of data sources, the reader is referred to Holguín-Veras et al. (2010). Among them, the CFS data and the ZIP code Business Pattern (ZCBP) data are of great importance to FG/FTG modeling, although they are not currently used for FG/FTG. The team is developing a proposal to the United States Census Bureau to obtain access to these two types of data. CFS and ZCBP data are briefly reviewed in this section.

Commodity Flow Survey (CFS) Data

Among all data sources, the CFS data collected by the Census Bureau and the Bureau of Transportation Statistics every 5 years since 1993 is of particular importance to FG/FTG modeling. The CFS is a collaborative effort among the Census Bureau, U.S. Department of Commerce, the Bureau of Transportation Statistics, and U.S. Department of Transportation. The CFS collects data regarding cargos originating from selected types of businesses located in the 50 states and the District of Columbia (U.S. Census Bureau, 2010a). Table 85 summarizes the CFS data elements that were collected for the 2007 CFS survey. The table shows both the general information that is collected by CFS, and additional information that is required if the shipment is an export or hazardous material. For shipments that include more than one commodity, respondents are instructed to report the commodity that makes up the greatest percentage of the shipment's weight (U.S. Census Bureau 2010a).

The CFS has collected a massive amount of data. For instance, the CFS 2007 collected data from 100,000 establishments that were required to provide information about all shipments for four different periods of 1 week of the year. The CFS data are used to produce the standard tabulations of commodity flows

Table 85. CFS data elements.

Shipment Types	Data collected
General	Domestic destination or port of exit
	Commodity
	Value
	Weight
	Mode(s) of transportation
	Date of shipment
	Indication of whether the shipment was an export or hazardous material
Exports	Mode of export
	Foreign destination city
	Country
Hazardous materials	UN/NA code *

*: UN: United Nation number; NA: North America number

Copyright National Academy of Sciences. All rights reserved.

at the current stage. The data from the CFS are currently also used by public policy analysts, and by transportation planners and decision-makers to assess the demand for transportation facilities and services, to assess energy use, safety risks and environmental concerns (U.S. Census Bureau 2010a). The CFS data however have not been widely used for freight modeling. Expanding the use of the CFS micro-data to estimate parameters of freight demand models would, at the same time, enhance the usefulness of the CFS, making it easier for practitioners to estimate freight demand models, and providing a significant boost to freight transportation modeling research by making available high quality data.

ZIP Code Business Patterns (ZCBP)

ZIP code Business Patterns (ZCBP) is one of the three programs developed by the Census Bureau to cover most of the country's economic activities. (The other two are County Business Patterns and Metro Business Patterns.) As described by U.S. Census Bureau (2010b): "County Business Patterns is an annual series that provides sub-national economic data by industry. The series is useful for studying the economic activity of small areas; analyzing economic changes over time; and as a benchmark for statistical series, surveys, and databases between economic censuses." The ZCBP data is crucial since "Businesses use the data for analyzing market potential, measuring the effectiveness of sales and advertising programs, setting sales quotas, and developing budgets. Government agencies use the data for administration and planning." ZCBP data include the number of establishments, number of employees, and payroll data by NAICS industry. ZCBP data were first available in 1994, and the most recent release for this dataset was 2007.

Secondary Data Sources

Secondary data sources include data related to ITS and GPS, which are of increasing importance to FTG and other types of freight-related modeling. There are, however, some obvious challenges, as stated in the NCHRP Synthesis 298: ". . . until these technologies are in wider use, their application to truck trip generation data will be limited." The freight industry has been a pioneer in using GPS for dynamic management of large fleets. As a result, over the years, a large amount of GPS data has been accumulated. However, the use of these data for FTG modeling has been relatively sparse. Similar issues apply to ITS data. There are a number of underlying reasons: (1) the proprietary and commercially sensitive nature of the data, which prevents the sharing of the data among different interest groups (e.g., data owners, decision-makers, practitioners, and researchers); (2) although highly accurate, the data do not contain much information of the kind transportation modelers need to build meaningful models (e.g., trip purposes, company characteristics); and (3) the level of penetration is still relatively small toward large and sophisticated companies.

However, it is important to recognize that data from secondary sources could be useful. GPS provides accurate information about a delivery tour (e.g., number of stops, dwell times) and travel times of individual vehicles that, as noted by *NCHRP Report 298*, are important, and usually hard to obtain via other data collection means. GPS data can also provide estimation of the temporal distribution of freight generated at an origin. For instance, GPS logs can provide an exact count of FTG produced by the distribution center if all vehicles are equipped with GPS. This may significantly reduce data collection efforts as the only thing needed is data describing the company characteristics. On the other hand, since GPS data are usually samples, they only provide a partial picture of the freight traffic. As small carriers are less likely to equip their fleet with GPS monitoring systems, GPS data can be biased since they tend to reflect the delivery patterns of large companies.

Table 86 summarizes the use of ITS data and GPS traces in FTG modeling, as well as their advantages and disadvantages. In general, ITS and GPS data can be used to calibrate various FTG models such as estimation of model parameters. The GPS traces can also be used to estimate the tours of delivery vehicles, such as the stops along the tour, dwell times, and paths of a specific tour, which are useful for developing FTG models that integrate both commodity-based and trip-based formulations.

Table 86. ITS and GPS data, and their use in FTG modeling.

Data class	Use in FTG modeling	Advantages	Disadvantages
ITS – vehicle classification data (i.e., vehicle mixes), truck counts, traffic travel times, network travel time or delay	Model calibration	Accurate	Aggregated information
		Can be automatically collected	Hard to infer individual behavior
GPS traces	Model calibration	Accurate	Privacy/proprietary
	Estimation of delivery tours	Can be automatically collected	Not representative (sparse samples or biased)
			Computationally expensive (large amount of data)

Copyright National Academy of Sciences. All rights reserved.

When using ITS or GPS data, one should recognize that the data do not have direct connections to characteristics of freight trips such as shipment purposes, and shipment type or size. Therefore, they should be used with care; particularly one should provide appropriate freight contents to ITS and GPS data, and make sure these data can be "explained" from freight activity perspectives before being used in FTG modeling. Ideally additional data that are directly related to freight trips should be collected, for use with the ITS and GPS data, so that the connections between ITS/GPS data and freight trips can be established. One example is to collect GPS traces in combination with travel diaries. In this way, not only stops and dwell times of a tour are collected, but also the purpose and delivery amounts at each stop along the tour. This will provide a more complete picture of a delivery tour, one which could be valuable in developing more advanced/accurate freight FTG models.

Summary

There is lack of primary FG/FTG data. This lack of primary data is a major issue because of the need to effectively incorporate freight transportation into the planning process. The fact that many of the sources of FTG models are now dated, and that one of the most important primary freight data sources, the CFS, has not been widely used for freight modeling only exacerbates this problem.

Copyright National Academy of Sciences. All rights reserved.

APPENDIX G

FG/FTG Models Relational Database Manual

In most cases, it is possible to store and maintain records using simple spreadsheets or word processing tools. When data becomes more complex and the user desires more functionality, a relational database management system becomes very useful. The Reference and Model Database constructed as part of NCFRP Project 25, "Freight Trip Generation and Land Use" (referred to as Database hereafter in this document) intends to assemble an online relational database of FG and FTG models (e.g., trip rates, regression models), publications, and case studies related to FTG. The Database is designed so that it does the following:

- Be stored and made available on the Internet, which would enable practitioners and researchers to have access to it when needed.
- Be integrated with an expert system that, in return to a query about trip rates, would provide the closest match.
- Enable practitioners and researchers to add data, after passing a quality assurance protocol.

The Database constructed was designed in Microsoft Access and contains three primary tables: Publications, Models, and Case Studies. The relationship of the three tables is shown in Figure 20.

The **Publications table** contains information about existing papers, reports, and/or books that are related to FG/FTG, including typical bibliographic information such as author list, year of publication, journal, title, page number, as well as fields indicating whether a particular reference contains FG/FTG case studies and/or models. It also contains a source number as its unique identifier. If a reference contains specific FG/FTG cases studies or models, such information will be used to construct the case study table and Model table. In other words, one reference can have many case studies and many models. Sometimes one case study may also have many models, as shown in the Figure 20.

The **Case Study table** is constructed by summarizing all the case studies in the references in the Reference table. The table contains fields such as project title, where the case study was reported, table/chapter title, where the case study was mentioned in the particular project report, and the city, state, and country where the case study was conducted. It also contains a source number in Reference table indicting the reference where the case study was reported.

The **Models table** is constructed by summarizing the FG/FTG models reported in the references or case studies. A model could be a trip rate, or other type of FG/FGT model, such as regression model, time series model, or neural-network model, among others. The table contains fields in terms of:

- Level of aggregation: aggregated, disaggregated.
- Level of geography: zonal/urban, regional, national, corridor, special facilities.
- Estimation technique: trip rates, Ordinary Least Square, spatial regression, MCA, trend and time series, IO, neutral network, growth rates, others, and not specified.
- Model structure: linear, nonlinear.
- Time unit: per day, per week, not specified.
- Model type: production model, attraction model, not specified.
- Dependent variables: the database includes the variable names as found in the source documents, which resulted in a large number of variables. The user is referred to the supplemental material of this Appendix, available online,[11] for a list of available variables.
- Independent variables: the database includes the variable names as found in the source documents, which resulted in a large number of variables. To ease the use and identification of these variables, they are further classified in terms of a qualifier (e.g., variable type), and the industry

[11]Available at http://transp.rpi.edu/~NCFRP25/Appendix_G_-_Variables.pdf

Copyright National Academy of Sciences. All rights reserved.

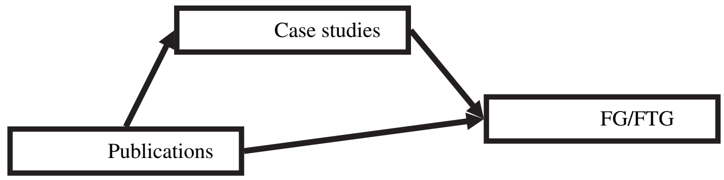


Figure 20. Database components.

sector (e.g., SIC code) or land use. (The reader is referred to variables supplemental material of this Appendix, available online, for a complete list of the individual variable classifications.) Taking into consideration the large combinatorial number of possible variables, an aggregation procedure for this classification was implemented, specifically for the variable type and qualifier.

– Variable type aggregations include: employment, area, establishment, household, individuals, travel time, fleet, industry segment, income, land use, parking, traffic volumes, sales, cargo, and other.
– The qualifiers include: agriculture, forestry and fisheries, mineral industries, construction industries; manufacturing; transportation, communication and utilities; wholesale trade; retail trade; food; finance, insurance, real estate, service industries, public administration; and land use.

In addition, each model contains a source number from the Reference table to link it to the reference where the model was proposed.

As of the production of this manual, there are 63 references included in the database (See the supplemental material of this Appendix, available online,[12] for a list of references included.); 23 of these references provide descriptions of case studies. A total of 292 case studies are described. The references and case studies identified provided 1890 distinct FG/FTG models. (Again, for a list of all models with basic information see the supplemental material of this Appendix, available online.[13])

One advantage of using a relational database to store and describe references, case studies, and models is that the user can query the database tables to extract specific information. For example, a user may be interested in knowing the trip rates for restaurants in the State of New York. In this case, the Database provides specific visual tools that allow the user to input the query and retrieve query results in a user-friendly manner.

This document is provided as a reference guide for using the Database. The document briefly explains the basics of opening the Database, how to navigate through the different sections (e.g., models, references and case studies) and provides a usability walkthrough explaining the following examples:

1. Trip rates and OLS on employment and food.
2. Production model under trip rates and OLS on employment.
3. Search publications on research papers, any independent variable, and employment.

Using the NCFRP 25 Reference and Model Database

Open the Database: Double click the icon of the Microsoft Access file containing the Database. If the security warning appears, click the "Options" button (see Figure 21) and enable all content in database. Click the "OK" button.

The *switchboard* automatically loads upon opening the database. This form allows the user to navigate through the database. The switchboard (see Figure 22) directs the user to choose between model, publications, or case study databases. The user is also able to close the database from here.

Each of the three modules of the database includes search, view, edit, and add capabilities described in this manual. These capabilities, as their names suggest, allow the user to find, modify, and add information to the database.

Go to Model Database

This module of the database allows for the viewing and managing of the models (Figure 23). Depending upon the specific needs of the user, a new source may be entered, models may be sorted using specified criteria, or a general listing of the models in the database may be viewed.

View all Models will open the entire list of models available on the database. To edit models, it is necessary to identify the model to be modified, and then make the corrections. To save the modifications made, click on "Edit model" button. Adding a new model is possible if an existing publication or case study has been previously added. Therefore, before adding a new model, it is necessary to add either a new publication or a case study, as a new model must be added to an existing publication.

[12]Available at http://transp.rpi.edu/~NCFRP25/Appendix_G_-_Publications.pdf
[13]Available at http://transp.rpi.edu/~NCFRP25/Appendix_G_-_Models.pdf

Copyright National Academy of Sciences. All rights reserved.

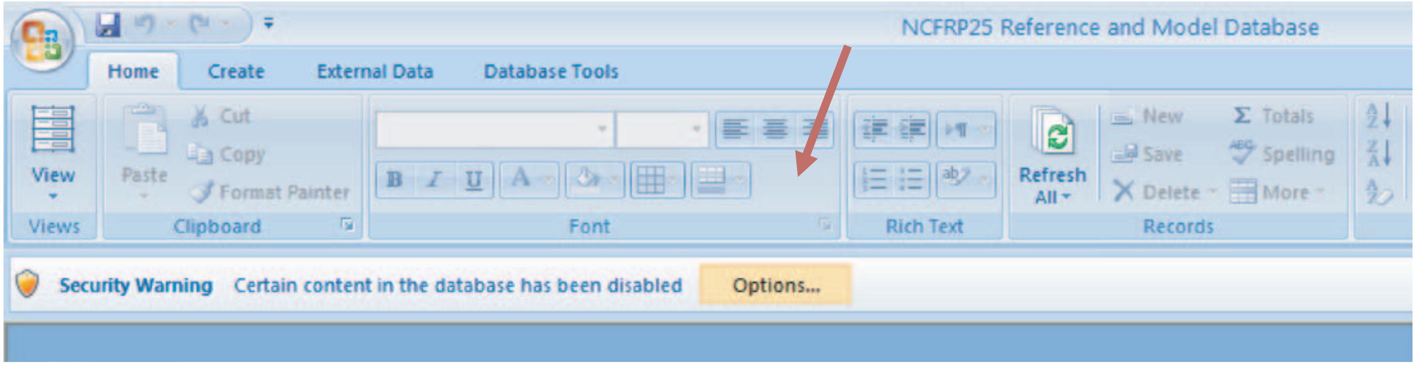


Figure 21. Opening the database.

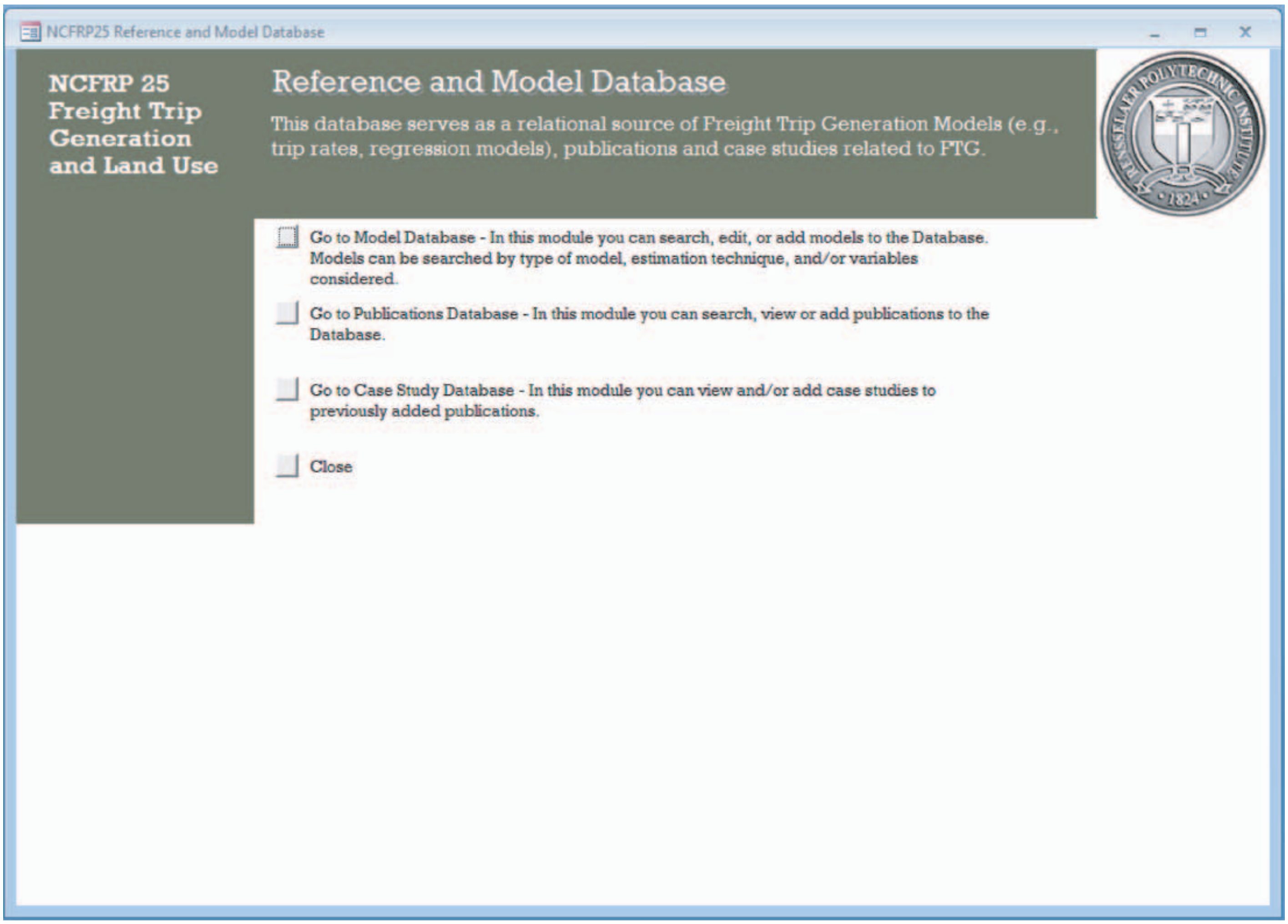


Figure 22. Database switchboard.

Copyright National Academy of Sciences. All rights reserved.

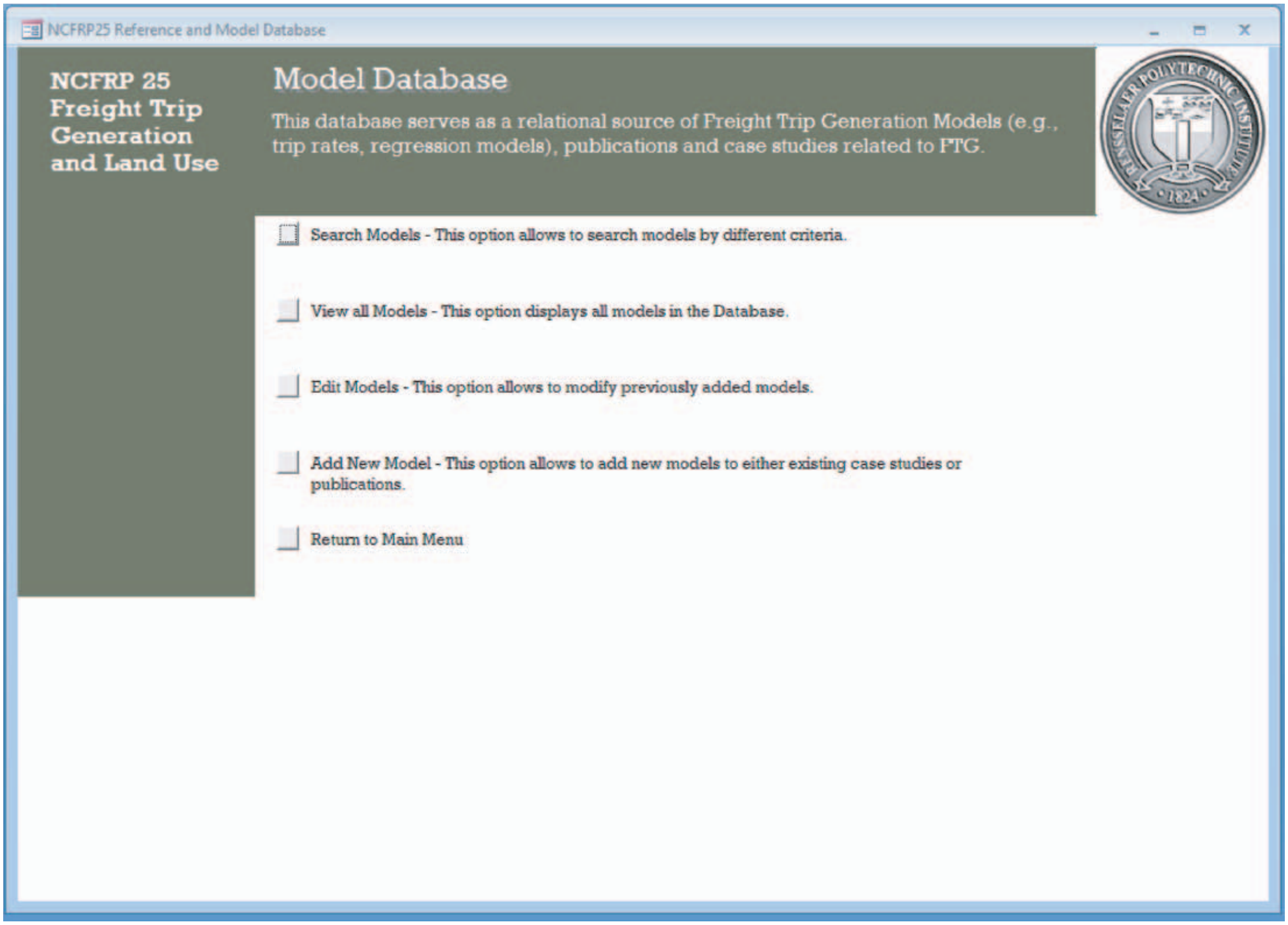


Figure 23. Model database switchboard.

When *Search Models* is selected, the user is directed to the form in which one can input the search criteria (see Figure 24). The user may select one option, multiple options, or no options from any of the five fields. To select multiple options, press "Ctrl" key and click on the desired options. It is important to stress that the linking options "and" and "or" allow the user to expand or restrict the search, respectively. In order to visualize the number of records of a specific search, the user must click the button "Number of records" located on the left, bottom corner of the switchboard. This feature allows the user to know in advance whether or not the search will show results. Another important characteristic is that the user can view complete, detailed information about each model from the search, or only a summary list with basic information.

When the *Add New Model* option is selected, the user is directed to the Model form. Figure 25 partially shows the different input options available to the user. It is possible to input several variables to specify the model being entered.

Go to the Publication Database

This module allows the user to visualize the publications (e.g., books, journal articles, reports) in the database, and with the same options as the model database (Figure 26).

View all Publications will show the entire list of publications with detailed information available on the database. *Add New Publications* allows the user to input the information for a new reference.

The *search publication* switchboard is shown in Figure 27. It includes three fields that can be chosen to select the type of publications of interest. As with the Search Models module, it is necessary to click the button "Number of records" to visualize this information before completing your search.

Go to the Case Study Database

When the "Go to Case Study Database" option is selected, the switchboard in Figure 28 is loaded. Since the purpose of the Database is to provide a source of FG/FTG models, the

Copyright National Academy of Sciences. All rights reserved.

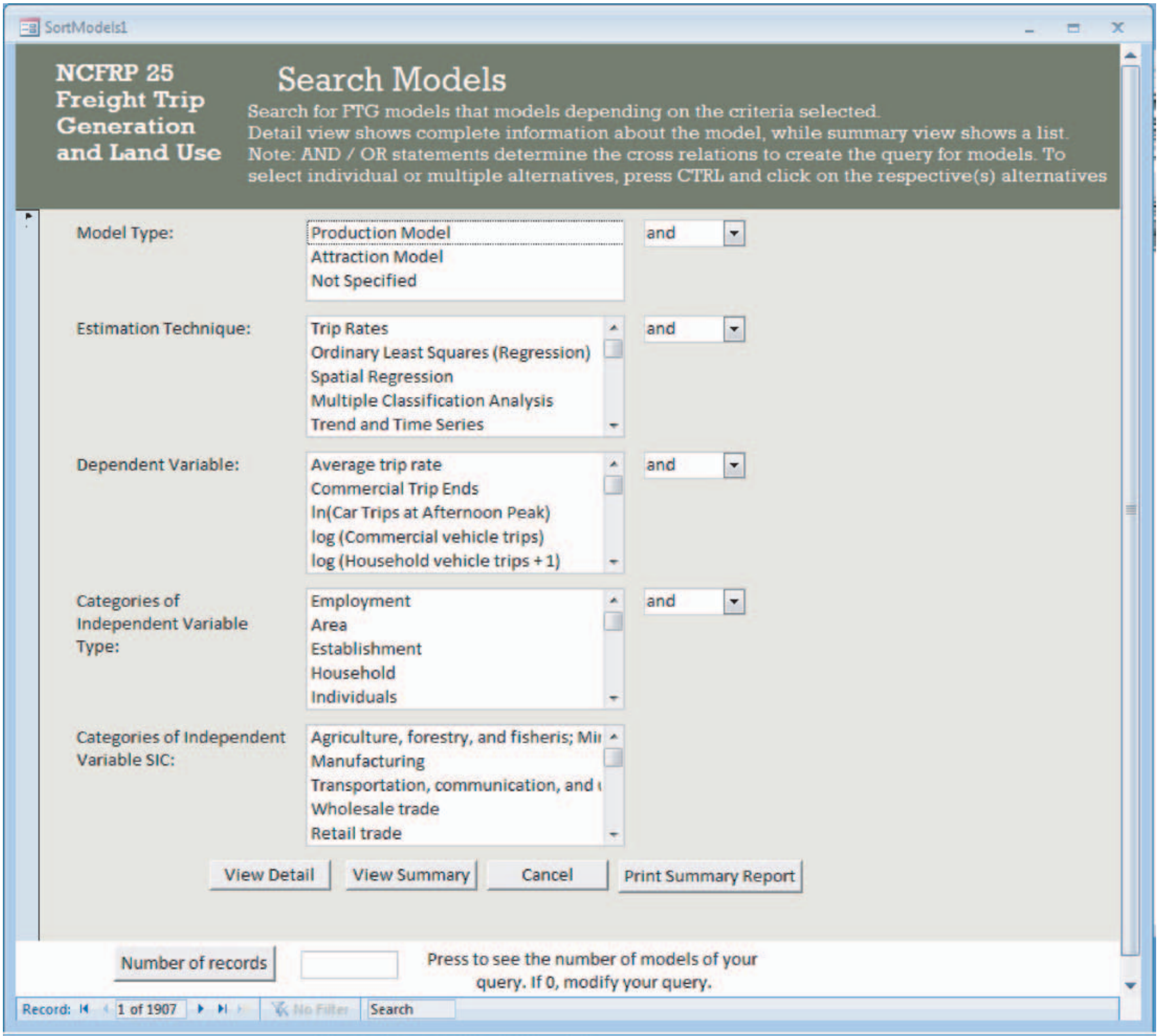


Figure 24. Options to search models in the database.

Copyright National Academy of Sciences. All rights reserved.

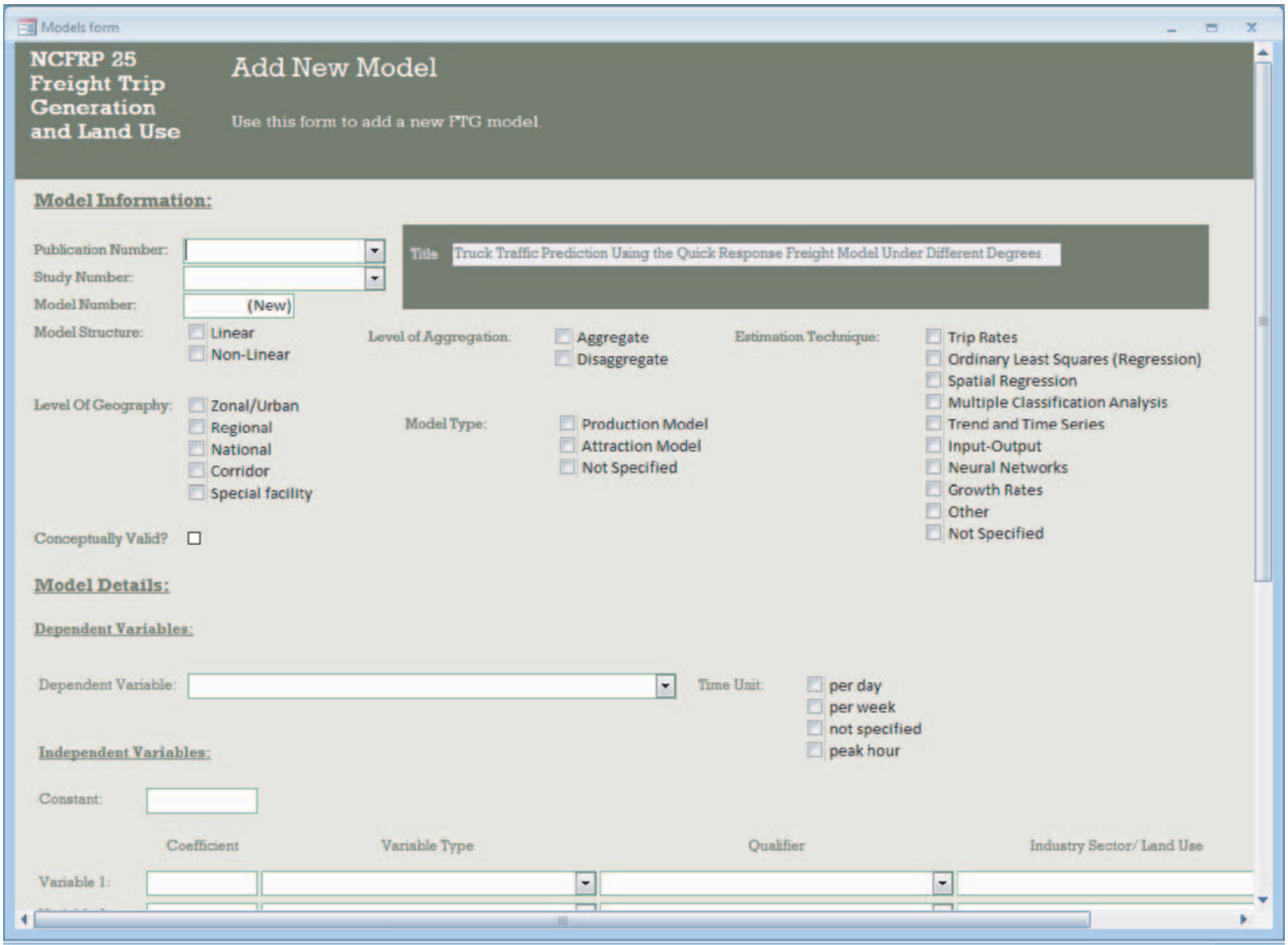


Figure 25. Add new model form.

Copyright National Academy of Sciences. All rights reserved.

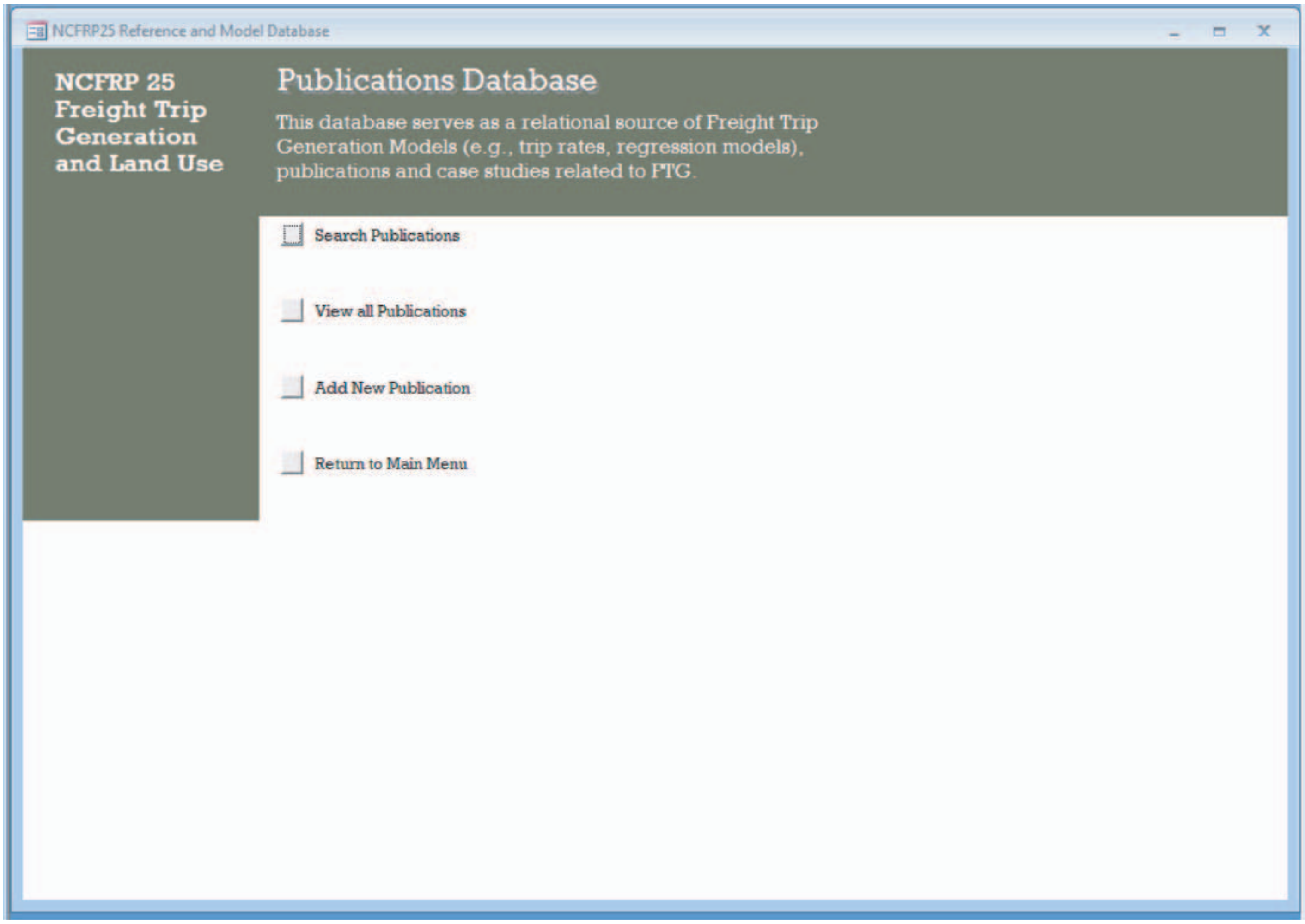


Figure 26. Publications database switchboard.

Copyright National Academy of Sciences. All rights reserved.

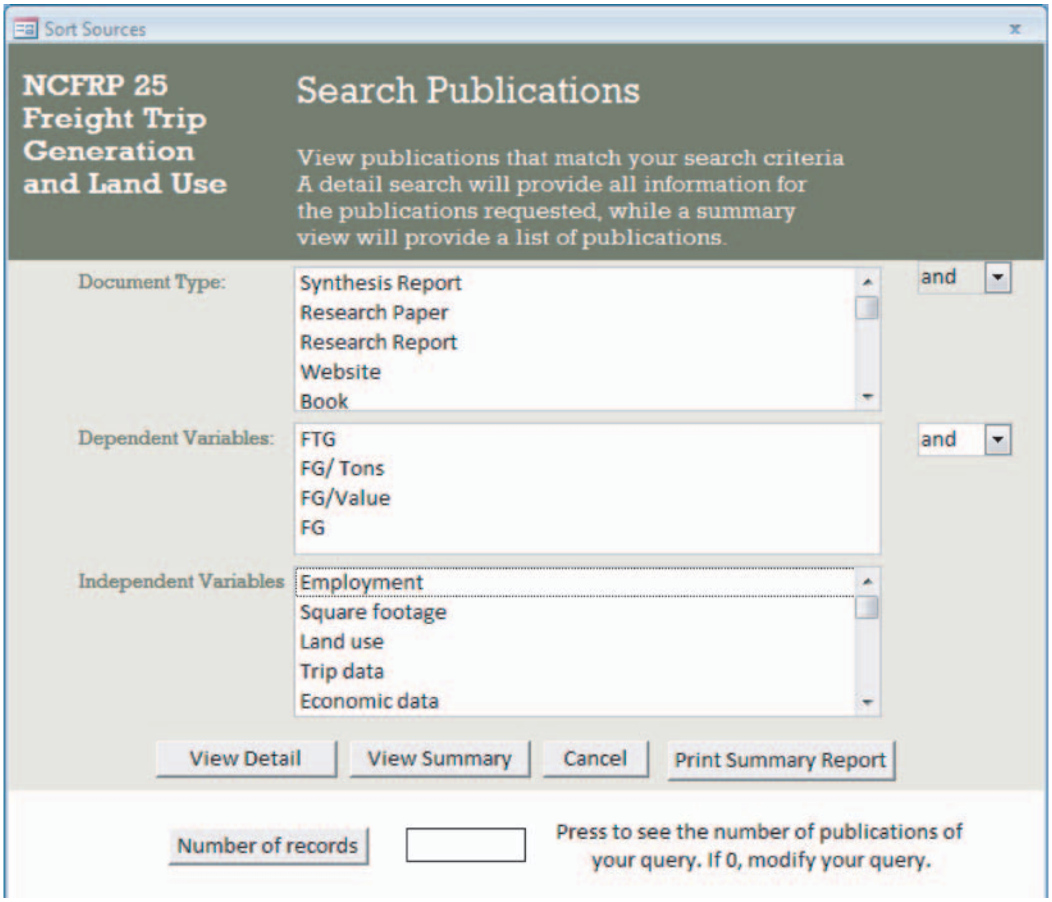


Figure 27. Search publication switchboard.

Copyright National Academy of Sciences. All rights reserved.

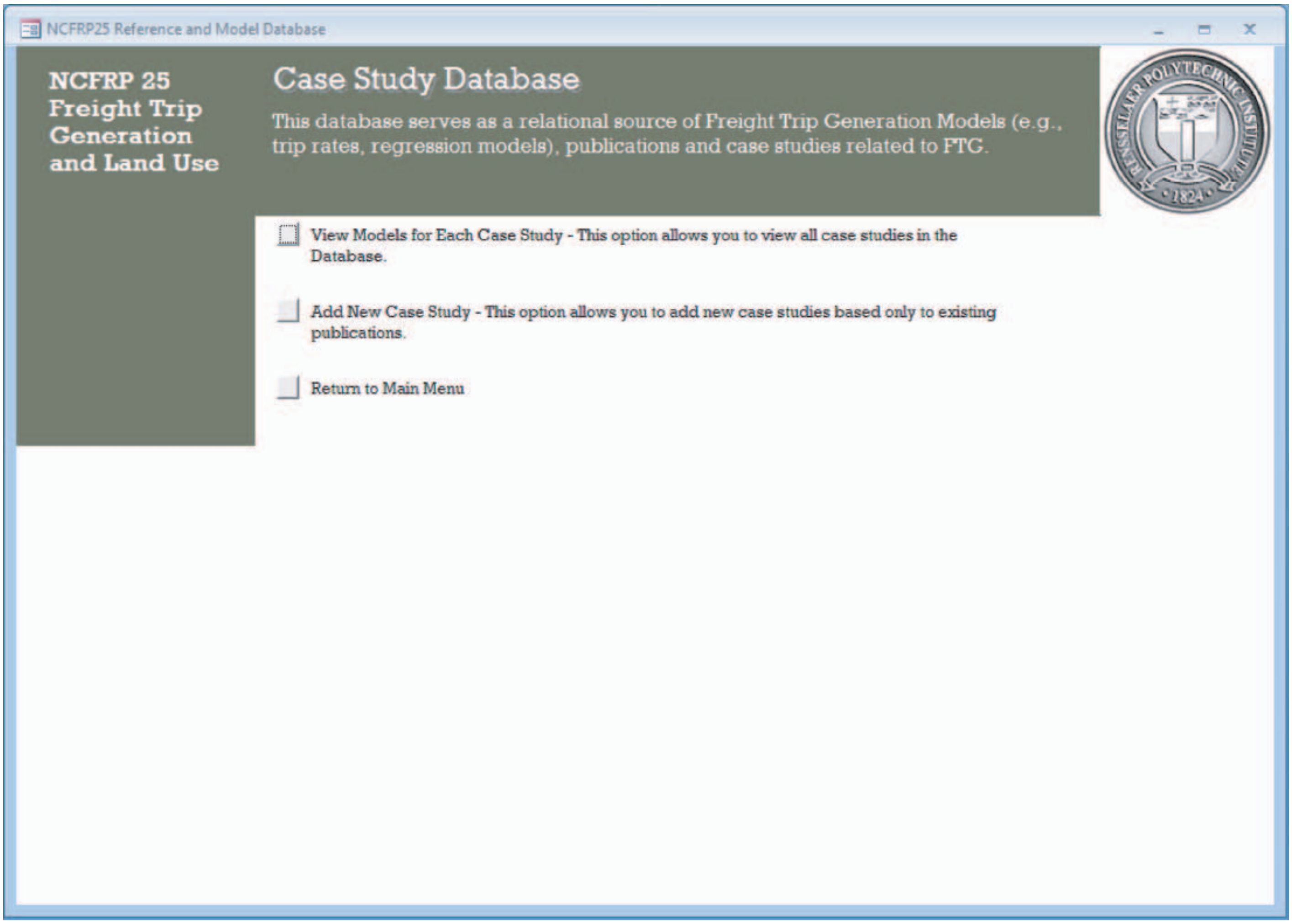


Figure 28. Case study switchboard.

Copyright National Academy of Sciences. All rights reserved.

first option available in this module is to view the models for each case study contained in the available publications. It is also possible to add a new case study, though to do so it is necessary to either add it to an existing publication, or first add a new publication and then incorporate the new case study into it. The following sections will provide a set of examples to show possible uses of the database.

Examples

This chapter includes two examples for searching specific models, and an example for searching publications. In general terms, the user must select a set of search criteria and then check the "number of records" of his/her search. If zero records appear, then the user should change the criteria to make it less restrictive. Finally, the user will have the option of viewing the complete detail or just a summary of the models, case studies, or publications that appear.

Example 1: Trip Rates and OLS on Employment and Food

This example searches all models included in the database, incorporating employment and food as independent variables in which the estimation technique can be either trips rates or OLS. Figure 29 shows the options from which the user needs to select for this search. Again, it bears repeating that to obtain the number of models contained in this search "Number of records" must be clicked.

Once the respective alternatives are selected, the user has the option of viewing the complete detail, or just a summary of the models. Figure 31 and Figure 30 show each of them respectively. It can be seen that this search will produce 10 records. It is also possible, from the completed search page, to print the summary report.

As shown in Figure 29, the conditional "and" is selected. The purpose is to query for models with the specified characteristics: they are either trip rates or OLS regression models and independent variable type is employment, select industry sector is food.

Example 2: Production Model Under Trip Rates and OLS on Employment

This example is similar to the previous, as the user is searching for models. In this case, the purpose is to obtain trip rates or OLS regression freight/freight trip production models that are dependent on employment. The number of records is larger in this instance than the previous because the user has unselected food. Therefore, the database will show the models for any category of independent variable or SIC. The selection criteria are shown in Figure 32. Summary results are shown in Figure 33, and detailed results are shown in Figure 34.

Example 3: Search Publications on Research Papers, Any Independent Variable, and Employment

In this example the user can obtain the set of publications including different criteria. Document type and either independent or dependent variables are the alternatives to be selected. In a similar fashion to models, it is possible to visualize and/or view the detail of the publications. Figure 35 shows these fields in detail, depicting the current search example: all research papers where the independent variable is employment. The summary of publications and detailed results are shown in Figure 36 and Figure 37, respectively.

Copyright National Academy of Sciences. All rights reserved.

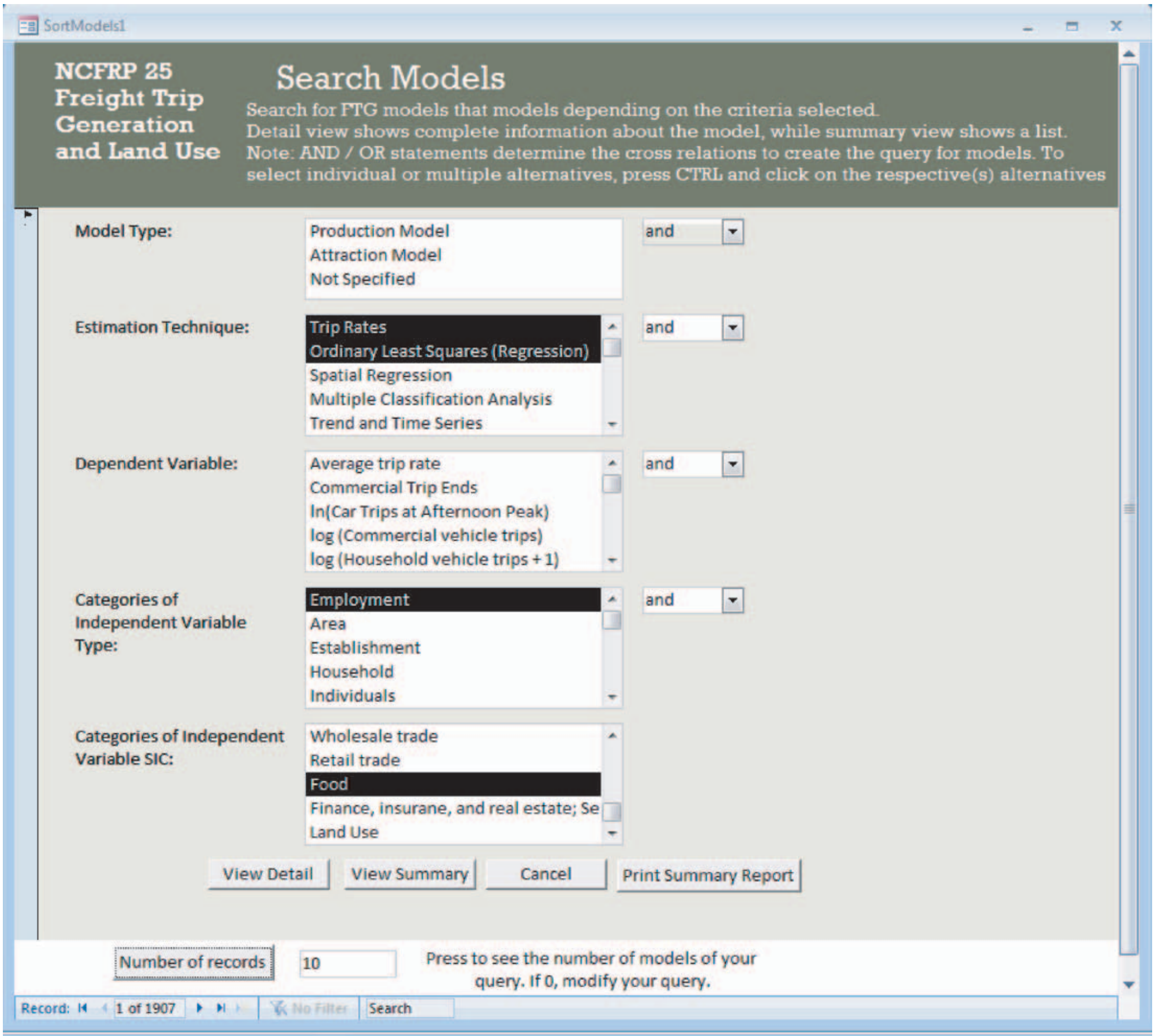
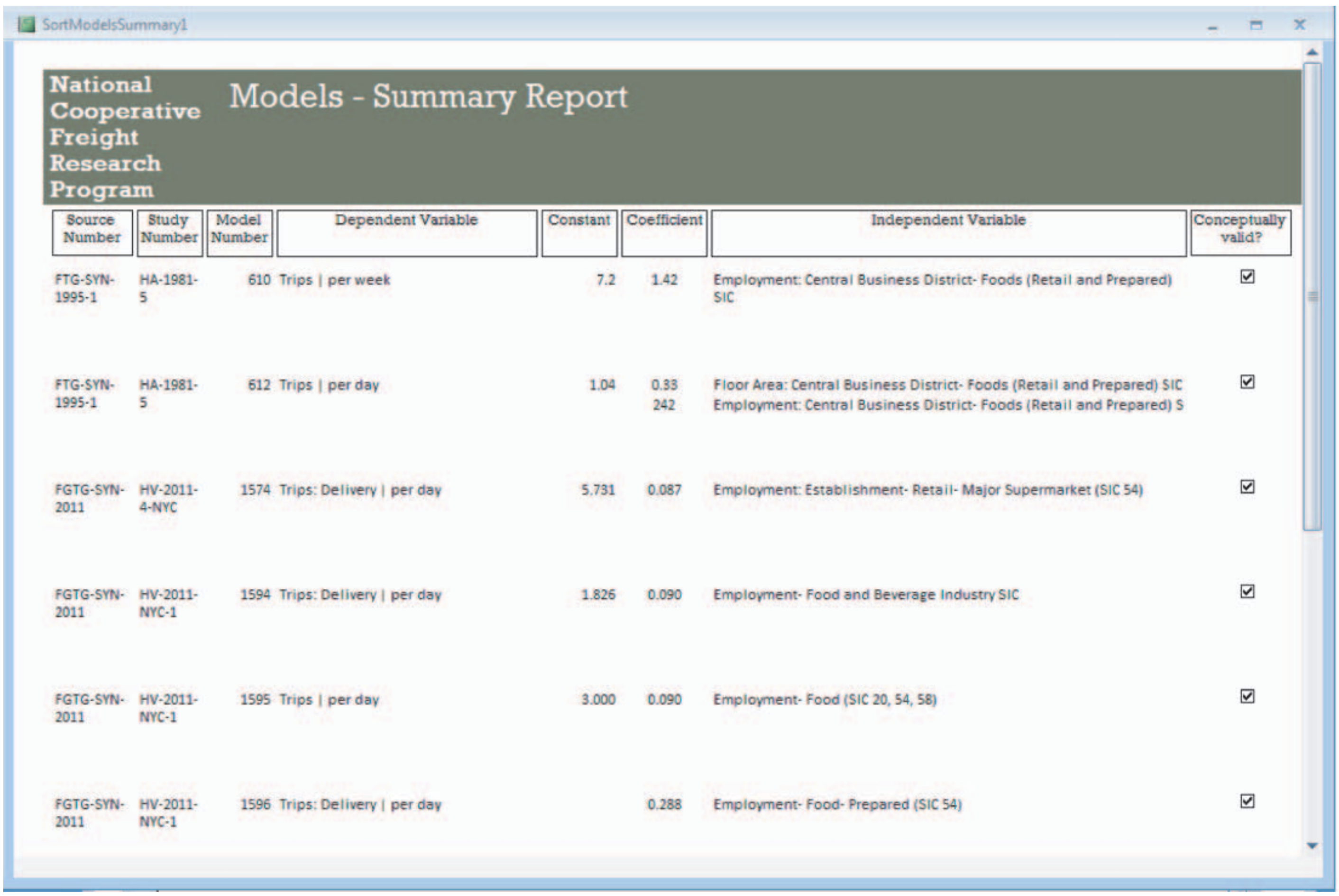


Figure 29. Search on models example 1.

Copyright National Academy of Sciences. All rights reserved.



SortModelsSummary1

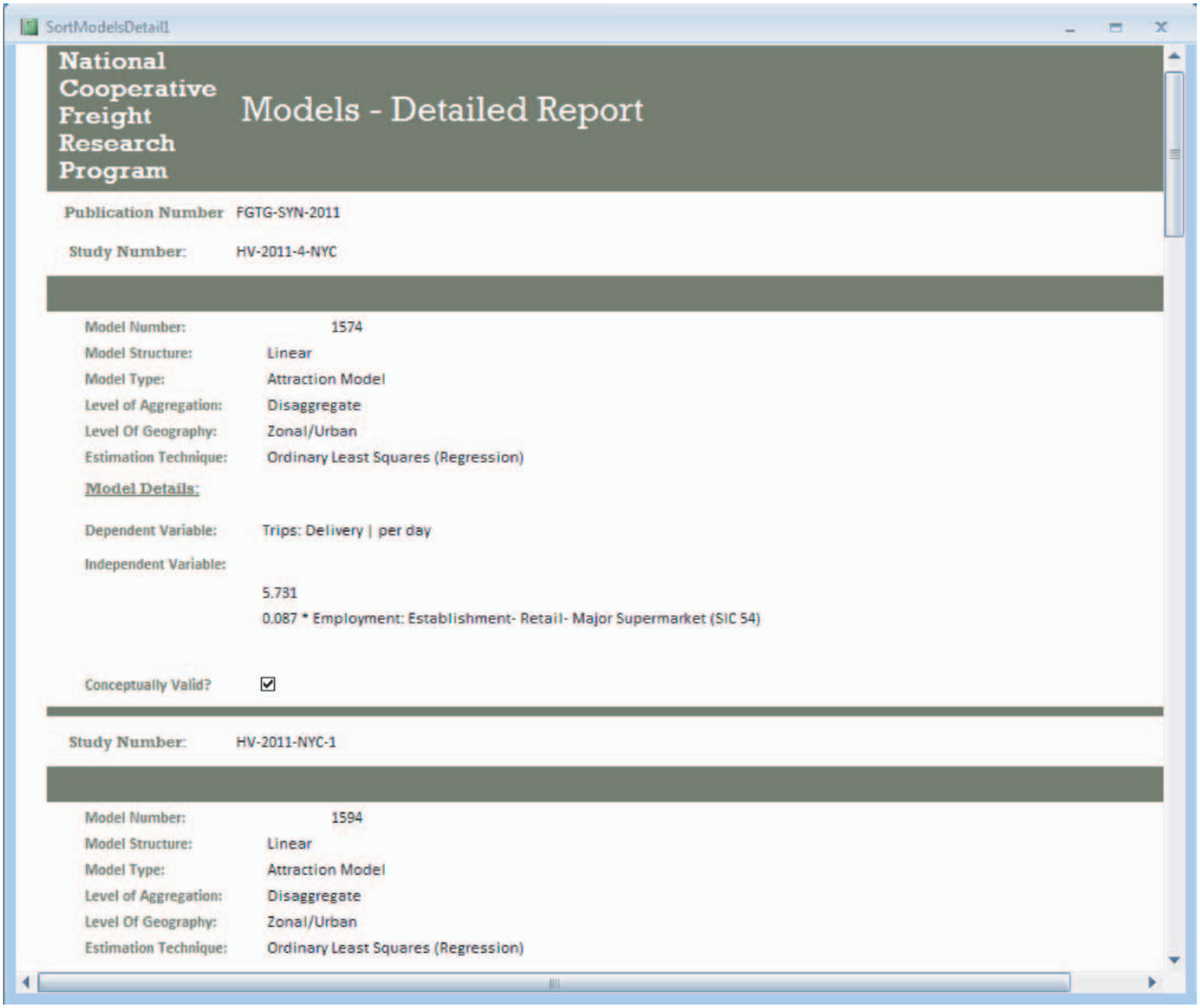
National Cooperative Freight Research Program

Models - Summary Report

Source Number	Study Number	Model Number	Dependent Variable	Constant	Coefficient	Independent Variable	Conceptually valid?
FTG-SYN-1995-1	HA-1981-5	610	Trips | per week	7.2	1.42	Employment: Central Business District- Foods (Retail and Prepared) SIC	☑
FTG-SYN-1995-1	HA-1981-5	612	Trips | per day	1.04	0.33 242	Floor Area: Central Business District- Foods (Retail and Prepared) SIC Employment: Central Business District- Foods (Retail and Prepared) S	☑
FGTG-SYN-2011	HV-2011-4-NYC	1574	Trips: Delivery | per day	5.731	0.087	Employment: Establishment- Retail- Major Supermarket (SIC 54)	☑
FGTG-SYN-2011	HV-2011-NYC-1	1594	Trips: Delivery | per day	1.826	0.090	Employment- Food and Beverage Industry SIC	☑
FGTG-SYN-2011	HV-2011-NYC-1	1595	Trips | per day	3.000	0.090	Employment- Food (SIC 20, 54, 58)	☑
FGTG-SYN-2011	HV-2011-NYC-1	1596	Trips: Delivery | per day		0.288	Employment- Food- Prepared (SIC 54)	☑

Figure 30. Summary report example 1.

Copyright National Academy of Sciences. All rights reserved.


SortModelsDetail1

National Cooperative Freight Research Program

Models - Detailed Report

Publication Number FGTG-SYN-2011

Study Number: HV-2011-4-NYC

Model Number: 1574
Model Structure: Linear
Model Type: Attraction Model
Level of Aggregation: Disaggregate
Level Of Geography: Zonal/Urban
Estimation Technique: Ordinary Least Squares (Regression)

Model Details:

Dependent Variable: Trips: Delivery | per day

Independent Variable:

5.731
0.087 * Employment: Establishment- Retail- Major Supermarket (SIC 54)

Conceptually Valid? ☑

Study Number: HV-2011-NYC-1

Model Number: 1594
Model Structure: Linear
Model Type: Attraction Model
Level of Aggregation: Disaggregate
Level Of Geography: Zonal/Urban
Estimation Technique: Ordinary Least Squares (Regression)

Figure 31. Detailed report example 1.

Copyright National Academy of Sciences. All rights reserved.

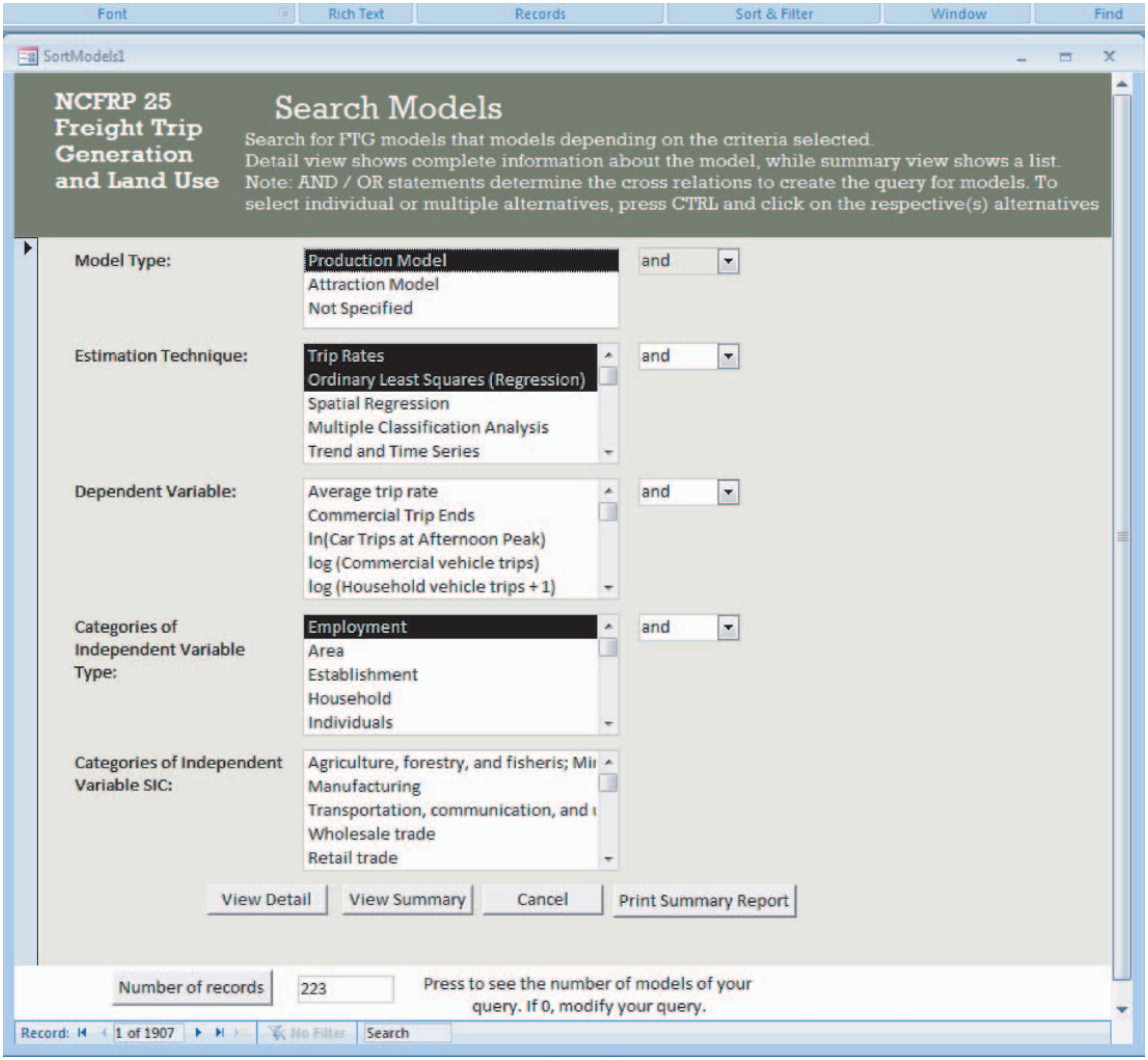
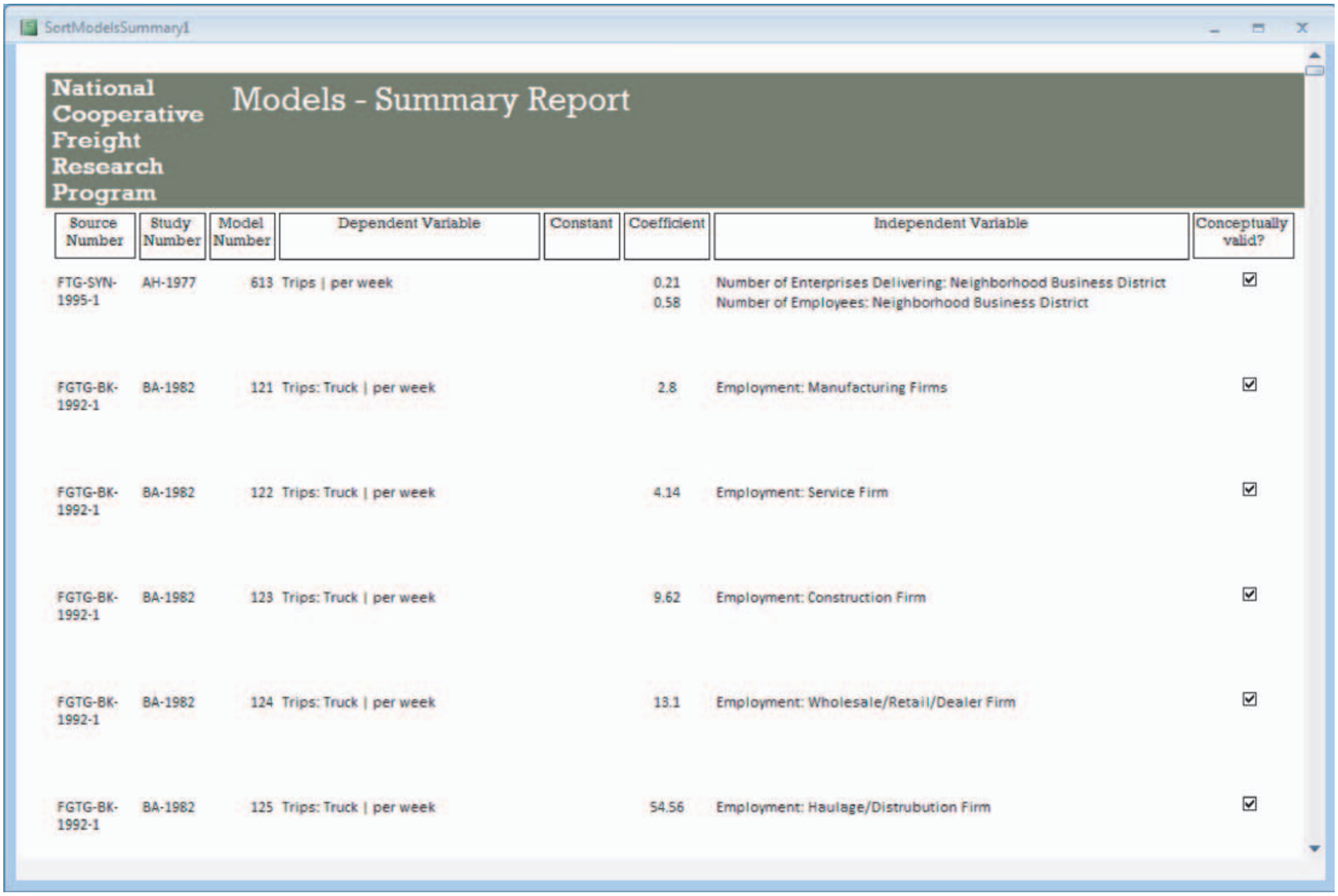


Figure 32. Search on example 2.



SortModelsSummary1

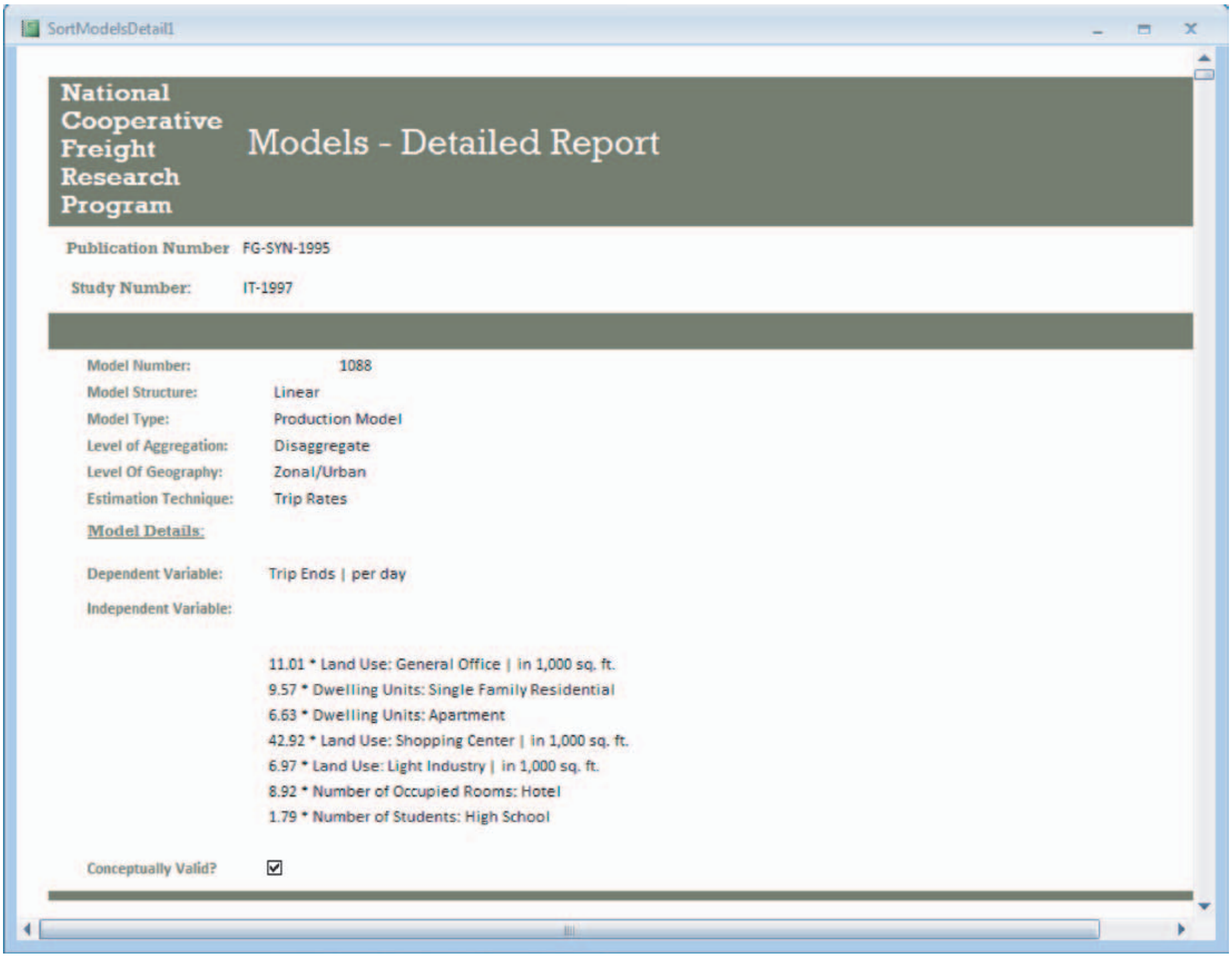
National Cooperative Freight Research Program

Models - Summary Report

Source Number	Study Number	Model Number	Dependent Variable	Constant	Coefficient	Independent Variable	Conceptually valid?
FTG-SYN-1995-1	AH-1977	613	Trips | per week		0.21 0.58	Number of Enterprises Delivering: Neighborhood Business District Number of Employees: Neighborhood Business District	☑
FGTG-BK-1992-1	BA-1982	121	Trips: Truck | per week		2.8	Employment: Manufacturing Firms	☑
FGTG-BK-1992-1	BA-1982	122	Trips: Truck | per week		4.14	Employment: Service Firm	☑
FGTG-BK-1992-1	BA-1982	123	Trips: Truck | per week		9.62	Employment: Construction Firm	☑
FGTG-BK-1992-1	BA-1982	124	Trips: Truck | per week		13.1	Employment: Wholesale/Retail/Dealer Firm	☑
FGTG-BK-1992-1	BA-1982	125	Trips: Truck | per week		54.56	Employment: Haulage/Distrubution Firm	☑

Figure 33. Summary report on example 2.

Copyright National Academy of Sciences. All rights reserved.



SortModelsDetail1

National Cooperative Freight Research Program

Models - Detailed Report

Publication Number FG-SYN-1995

Study Number: IT-1997

Model Number: 1088

Model Structure: Linear

Model Type: Production Model

Level of Aggregation: Disaggregate

Level Of Geography: Zonal/Urban

Estimation Technique: Trip Rates

Model Details:

Dependent Variable: Trip Ends | per day

Independent Variable:

11.01 * Land Use: General Office | in 1,000 sq. ft.
9.57 * Dwelling Units: Single Family Residential
6.63 * Dwelling Units: Apartment
42.92 * Land Use: Shopping Center | in 1,000 sq. ft.
6.97 * Land Use: Light Industry | in 1,000 sq. ft.
8.92 * Number of Occupied Rooms: Hotel
1.79 * Number of Students: High School

Conceptually Valid? ☑

Figure 34. Detailed report on example 2.

Copyright National Academy of Sciences. All rights reserved.

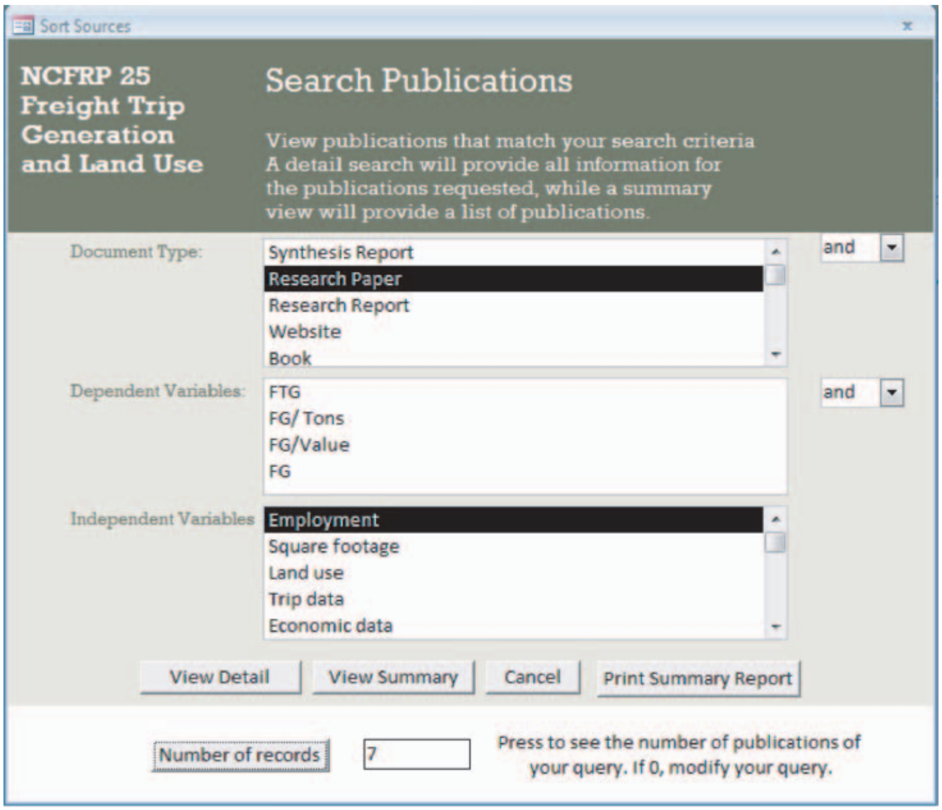
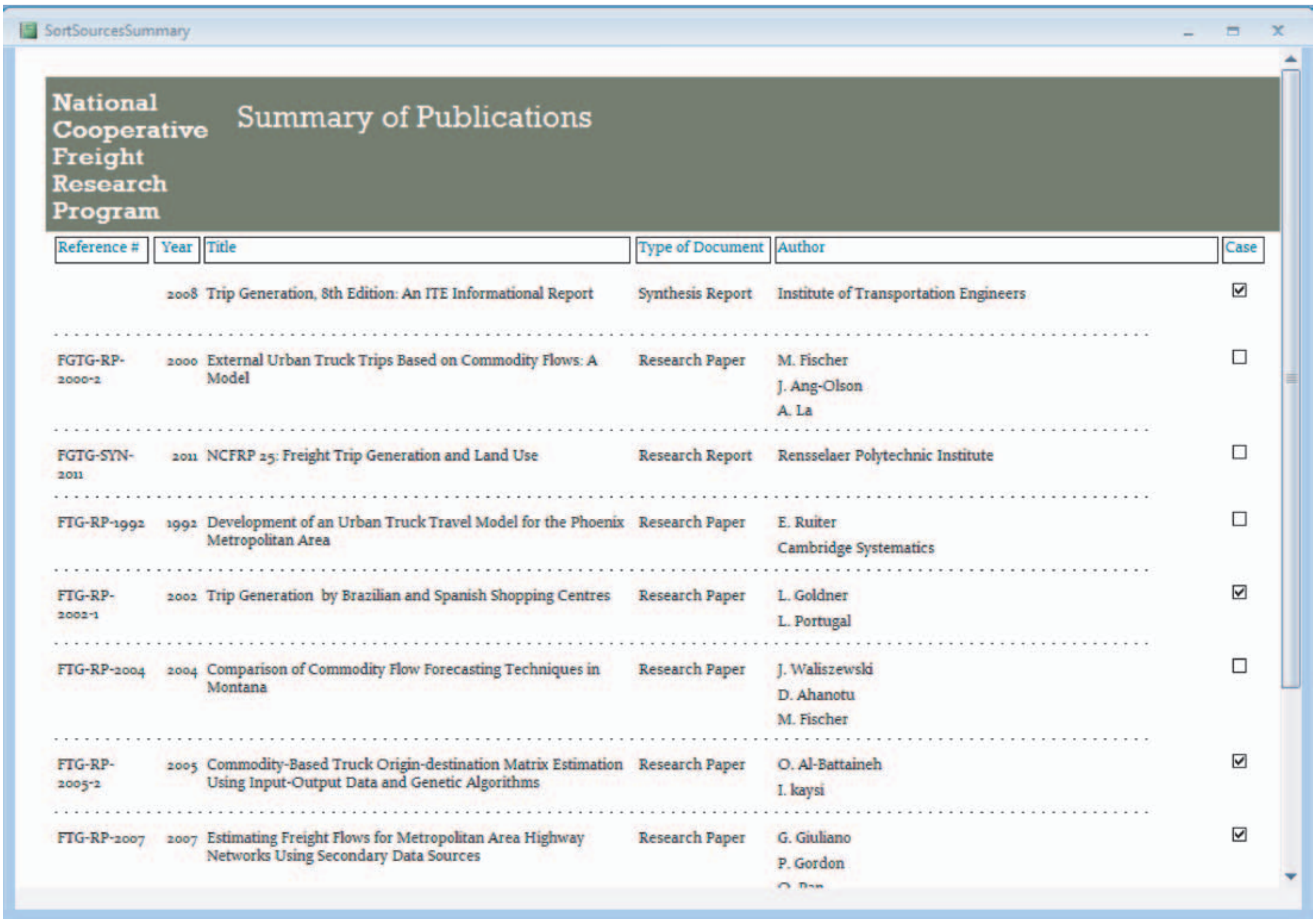


Figure 35. Search on publications.

Copyright National Academy of Sciences. All rights reserved.



SortSourcesSummary

National Cooperative Freight Research Program

Summary of Publications

Reference #	Year	Title	Type of Document	Author	Case
	2008	Trip Generation, 8th Edition: An ITE Informational Report	Synthesis Report	Institute of Transportation Engineers	☑
FGTG-RP-2000-2	2000	External Urban Truck Trips Based on Commodity Flows: A Model	Research Paper	M. Fischer J. Ang-Olson A. La	☐
FGTG-SYN-2011	2011	NCFRP 25: Freight Trip Generation and Land Use	Research Report	Rensselaer Polytechnic Institute	☐
FTG-RP-1992	1992	Development of an Urban Truck Travel Model for the Phoenix Metropolitan Area	Research Paper	E. Ruiter Cambridge Systematics	☐
FTG-RP-2002-1	2002	Trip Generation by Brazilian and Spanish Shopping Centres	Research Paper	L. Goldner L. Portugal	☑
FTG-RP-2004	2004	Comparison of Commodity Flow Forecasting Techniques in Montana	Research Paper	J. Waliszewski D. Ahanotu M. Fischer	☐
FTG-RP-2005-2	2005	Commodity-Based Truck Origin-destination Matrix Estimation Using Input-Output Data and Genetic Algorithms	Research Paper	O. Al-Battaineh I. kaysi	☑
FTG-RP-2007	2007	Estimating Freight Flows for Metropolitan Area Highway Networks Using Secondary Data Sources	Research Paper	G. Giuliano P. Gordon	☑

Figure 36. Summary of publications.

Copyright National Academy of Sciences. All rights reserved.

ReportSortSources

National Cooperative Freight Research Program

Detailed Information of Publications

Source Number:	FGTG-RP-2000-2
Year of Publication	2000
Title	External Urban Truck Trips Based on Commodity Flows: A Model
Author 1:	M. Fischer
Author 2:	J. Ang-Olson
Author 3:	A. La
Author 4:	
Author 5:	
Type of Document	Research Paper
Conference	
Project	
URL	http://dx.doi.org/10.3141/1707-09
Dependent Variables	FG/ Tons, FTG
Independent Variables	Commodity flows, Employment, Land use, Other
Level of Aggregation	Disaggregate
Geography Level	Regional
Estimation Technique	Input-Output
Model Structure	
Model Type	
Abstract	The purpose of the paper is to describe a procedure for incorporating inter
Remarks	

Figure 37. Detailed results in publication search.

Copyright National Academy of Sciences. All rights reserved.

APPENDIX H

Prototype Freight and Service Trip Generation Survey

Copyright National Academy of Sciences. All rights reserved.

Freight Trip Generation Study

Information you provide here will be kept confidential and will be used for planning purposes only

ESTABLISHMENT INFORMATION

Name:	____________	Address:	____________
City:	____________	State:	____________
ZIP:	____________		

CONTACT INFORMATION FOR THE PERSON COMPLETING THE SURVEY

Name:	____________	Position:	____________
Phone number:	____________	E-mail:	____________

BUSINESS ACTIVITY

Nature of business: Restaurants ☐ Food store ☐ Apparel/Accesory store ☐ Building materials ☐ Other: ____________

TYPE OF ESTABLISHMENT

Is this the headquarters of the firm? YES ☐ NO ☐

NUMBER OF PEOPLE CURRENTLY EMPLOYED AT THIS ADDRESS

	Full time	Part time
Total employees in a typical day (office + others)	________	________
Total office staff in a typical day	________	________

Is the work done at the premises performed in shifts? YES ☐ NO ☐

Total number of employees per shift: ____________

SITE AND GROSS FLOOR AREA

Is your establishment the only one at this site?	Total site area*	Establishment Floor Area*
NO	________	________
YES	N/A	________

* Specify units (e.g., sq. yds, sq. ft, acres)

Number of floors of the main building occupied by the firm: ________

NUMBER OF VEHICLES OPERATED FROM THIS ADDRESS BY TYPE

Notes: (1) Include leased vehicles. See the diagram of vehicle types in the next question.
(2) If you do not know the answer fill it in using "n/a"

Cars:	________	4 or fewer axle single-trailer trucks:	________
Small pickups/vans:	________	5 axle single or multi-trailer trucks:	________
2 axle single unit trucks:	________	6 or more axle single or multi-trailer trucks:	________
3 or 4 axle single unit trucks:	________	others/ not specified:	________

Copyright National Academy of Sciences. All rights reserved.

TRIPS RELATED TO GOODS AND SUPPLIES

NUMBER OF DELIVERY TRIPS WITH THIS ADDRESS AS ORIGIN OR DESTINATION BY VEHICLE TYPE

In the table below, provide the average number of deliveries PER DAY/ PER WEEK (e.g., office supplies and food)
If no information is available use "n/a". If the answer is zero use "0"

Description	Example	MADE FROM this address (deliveries to customers)	RECEIVED AT this address (deliveries to establishment)	Time unit
Cars				☐ per day ☐ per week
Small pickups/vans				☐ per day ☐ per week
2 axle single unit trucks				☐ per day ☐ per week
Large trucks				☐ per day ☐ per week
Other / Don't know				☐ per day ☐ per week

TYPE OF CARGO PRODUCED AND RECEIVED BY THE ESTABLISHMENT

Type of cargo produced	Quantity	Unit (e.g., tons, lbs)	Type of cargo received	Quantity	Unit (e.g., tons, lbs)
________	________	________	________	________	________
________	________	________	________	________	________
________	________	________	________	________	________

TRIPS RELATED TO SERVICES

NUMBER OF SERVICE TRIPS WITH THIS ADDRESS AS ORIGIN OR DESTINATION BY VEHICLE TYPE

In the table below, provide the average number of service trips PER DAY/ PER WEEK (e.g., cleaning the windows)
If no information is available use "n/a". If the answer is zero use "0"

Description	Example	LEAVING this address	RECEIVED AT this address	Time unit
Cars				☐ per day ☐ per week
Small pickups/vans				☐ per day ☐ per week
2 axle single unit trucks				☐ per day ☐ per week
Other / Don't know				☐ per day ☐ per week

If you would like more information about the survey, please contact Mr. xxxxx (xxxx@xxx.xxx) at his/her e-mail address or call xxx-xxx-xxxx

Copyright National Academy of Sciences. All rights reserved.

APPENDIX I

Case Studies

This section provides complementary tables for the case studies discussion.

Table 87. Employment distribution of receiver companies, NYC.

Number of employees	Number of companies	% of companies
5<	28	7.73%
5-9	102	28.18%
10-19	101	27.90%
20-49	92	25.41%
50-99	33	9.12%
100-249	6	1.66%
Total	**362**	**100.00%**

Table 88. Employment distribution of carrier companies, NYC.

Number of employees	Number of companies	% of companies
5<	41	12.09%
5-9	37	10.91%
10-19	49	14.45%
20-49	125	36.87%
50-99	60	17.70%
100-249	23	6.78%
250-750	4	1.18%
Total	**339**	

Table 89. Comparison of industry sectors (SIC and NAICS) for receivers and carriers.

Gr.	NAICS Code	2007 NAICS U.S. Title	SIC Codes	
			Receivers	Carriers
1	23	Construction	15, 16, 17	15, 17
2	31	Manufacturing	20, 22, 23*, 54*	20, 22, 23
	32		24*, 26, 27*, 30, 32	24*, 26, 27*, 30, 32, 39*
	33		23*, 24*, 25, 34, 35, 36, 38, 39	24*, 25, 33, 34, 35, 36, 38, 39*, 57
3	42	Wholesale Trade	50, 51	50, 51*
4	44	Retail Trade	52, 54*, 55, 56, 57, 59*	52, 55, 56, 59*
	45		59*	51*, 59*
5	48	Transportation and Warehousing		42*, 47
	49			42*
6	72	Accommodation and Food Services	58	58
7	51	Information	27*	27*
	56	Administrative and Support, Waste Management and Remediation Services	74	
	92	Public Administration	94, 96	94

Note: The * denotes SICs that belong to more than one NAICS within its respective sample

Copyright National Academy of Sciences. All rights reserved.

This table shows the hourly breakdown for the number of daily deliveries that each store receives. As shown, from 6 p.m. to 9 p.m. there are no deliveries made to these stores, with the bulk of the deliveries (about 85%) being made between 3 a.m. and 3 p.m.

Table 90. Number of daily deliveries per whole foods market store per time of day.

Delivery time	Chelsea							Union Square							Tribeca							Columbus Circle							Bowery							Total All Stores
	M	T	W	R	F	Sa	Su	M	T	W	R	F	Sa	Su	M	T	W	R	F	Sa	Su	M	T	W	R	F	Sa	Su	M	T	W	R	F	Sa	Su	
1 a.m.													1																1	1	1					4
2 a.m.								2	2	2	2	2	2	2	1	1	1	1	1	1							1					1	1		1	24
3 a.m.	3	3	3	3	3	3	3	1	2		2	1	1									1	1	1	1	1		1	4	4	4	1	1	1		49
4 a.m.	1	1	1	1	1	1	1	2	2	2	2	2	2	2							1	4	4	4	4	4	3	3	1	1	2	1				53
5 a.m.										1			1		2	3	3	3	2	2		3	3	4	3	4		1	1	3		1				40
6 a.m.	1	1	1	1	2			3	3	4	5	2	2	1	4	2	3	2	3	1		8	6	4	6	5	1	1	2			4	2	3		83
7 a.m.	4	2	3	3	3			3	2	3	3	3	2		1	1	1	1	1	1		3	5	3	3	3	3	1	3	2	2	1	1	3		70
8 a.m.	2		2			2		2	2	2	1	2	1		3	3	3	3	3	2		2	2	4	1	1	1		2	3	4	1	2	1	1	58
9 a.m.	4		4	3	2	2		1	1	1	1	1	1		1	1	2	1	2	2		1	5	3	1	2			2	2	2					48
10 a.m.	4	6	5	4	4	1			2						3	2	2	3	4	2		2	4	3	3	2			1	1	1	1		1		61
11 a.m.	3	5	2	5	5	1		3	4	3	3	4	1		2	8	8	3	9			2	5	2	2	1			2	1	2		2			88
12 p.m.	5	5	6	7	5	1		1	1	1		2			2	1	2	1	2			3	4	5	3	4			2	1	1	1			1	67
1 p.m.	4	2	6	3	3			1	2	1	1	1			5	5	2	5	4	2		3	3	3	3	4			2	3	2					70
2 p.m.		1	1		1			2	1	1	1	2											1		1	1			1	2	1	1	2			20
3 p.m.				1																		1	2	1	1	2							1	3		12
4 p.m.															1	1	1	1	1				1	1									1			8
5 p.m.																																		1		1
6 p.m.																																				0
7 p.m.																																				0
8 p.m.																																				0
9 p.m.																																				0
10 p.m.	1	1	1	1	1																	1	1	1	1	1		1								11
11 p.m.			1	1				5	4	6	5	8	1	2																						33
12 a.m.															3	4	3	2	5	1		1	1	1	1	1		1	1	1	1					27
Total	32	27	36	33	30	11	4	26	28	27	26	30	15	7	28	32	31	26	37	14	1	35	48	40	34	36	9	9	25	25	23	13	13	13	3	827

Table 91. SIC type of freight attraction FTG model per industry sector or group.

Type S: Deliveries /establishment	Type E: Deliveries/employee	Type C: Linear model
Group 3 (Construction Industries)	SIC 15 (Building Construction-General Contractors and Operative Builders)	Group 6 (Wholesale Trade)
SIC 17 (Construction-Special Trade Contractors)	SIC 24 (Lumber and Wood Products, Except Furniture)	SIC 51 (Wholesale Trade - Nondurable Goods)
Group 4 (Manufacturing)	SIC 52 (Building Materials, Hardware, Garden Supply, and Mobile Home)	Group 8 (Food)
SIC 25 (Furniture and Fixtures)	SIC 56 (Apparel and Accessory Stores)	SIC 58 (Eating and Drinking Places)
SIC 23 (Apparel and Other Finished Products Made From Fabrics and Similar Material)	SIC 54 (Food Stores)	
SIC 34 (Fabricated Metal Products, Except Machinery and Transportation Equipment)		
SIC 39 (Miscellaneous Manufacturing)		
SIC 50 (Wholesale Trade - Durable Goods		
Group 7 (Retail Trade)		
SIC 57 (Home Furniture, Furnishing, and Equipment Stores)		
SIC 59 (Miscellaneous Retail)		
SIC 20 (Food and Kindred Products)		

Copyright National Academy of Sciences. All rights reserved.

Table 92. SIC type of model per industry sector or group (freight trip production).

Type S: Deliveries /establishment	Type E: Deliveries/employee	Type C: Linear model
Group 4 (Manufacturing)	Group 3 (Construction Industries)	Group 5 (Transportation, Communications, and Utilities)
SIC 51 (Wholesale Trade - Nondurable Goods)	SIC 17 (Construction-Special Trade Contractors)	SIC 42 (Motor Freight Transportation and Warehousing)
Group 7 (Retail Trade)	SIC 47 (Transportation Services)	Group 6 (Wholesale Trade)
SIC 20 (Food and Kindred Products)	SIC 50 (Wholesale Trade - Durable Goods)	SIC 51 (Wholesale Trade - Nondurable Goods)
Group 8 (Food)		

Table 93. Area definitions from the tax-lot data.

Area			Description
Lot			Total area of the tax lot
Total Building Floor			The total gross floor area
	Residential Floor		* Residential purposes
	Commercial Floor		* Commercial purposes
		Office Floor	* Office purposes
		Retail Floor	* Retail purposes
		Garage Floor	* Garage purposes
		Storage Floor	* Storage purposes
		Factory Floor	* Factory/warehouse/ loft purposes
		Other Floor	* Uses other than previous purposes

* An estimate of the portion of the building(s) allocated for:

Copyright National Academy of Sciences. All rights reserved.

Abbreviations and acronyms used without definitions in TRB publications:

AAAE	American Association of Airport Executives
AASHO	American Association of State Highway Officials
AASHTO	American Association of State Highway and Transportation Officials
ACI–NA	Airports Council International–North America
ACRP	Airport Cooperative Research Program
ADA	Americans with Disabilities Act
APTA	American Public Transportation Association
ASCE	American Society of Civil Engineers
ASME	American Society of Mechanical Engineers
ASTM	American Society for Testing and Materials
ATA	American Trucking Associations
CTAA	Community Transportation Association of America
CTBSSP	Commercial Truck and Bus Safety Synthesis Program
DHS	Department of Homeland Security
DOE	Department of Energy
EPA	Environmental Protection Agency
FAA	Federal Aviation Administration
FHWA	Federal Highway Administration
FMCSA	Federal Motor Carrier Safety Administration
FRA	Federal Railroad Administration
FTA	Federal Transit Administration
HMCRP	Hazardous Materials Cooperative Research Program
IEEE	Institute of Electrical and Electronics Engineers
ISTEA	Intermodal Surface Transportation Efficiency Act of 1991
ITE	Institute of Transportation Engineers
NASA	National Aeronautics and Space Administration
NASAO	National Association of State Aviation Officials
NCFRP	National Cooperative Freight Research Program
NCHRP	National Cooperative Highway Research Program
NHTSA	National Highway Traffic Safety Administration
NTSB	National Transportation Safety Board
PHMSA	Pipeline and Hazardous Materials Safety Administration
RITA	Research and Innovative Technology Administration
SAE	Society of Automotive Engineers
SAFETEA-LU	Safe, Accountable, Flexible, Efficient Transportation Equity Act: A Legacy for Users (2005)
TCRP	Transit Cooperative Research Program
TEA-21	Transportation Equity Act for the 21st Century (1998)
TRB	Transportation Research Board
TSA	Transportation Security Administration
U.S.DOT	United States Department of Transportation

Copyright National Academy of Sciences. All rights reserved.