Simulating Human-Robot Collaboration
- An example from cab assembly

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Abstract

This is a master thesis report conducted at the Department of Production Engineering at KTH. The master thesis is a part of the ToMM (Collaborative Team of Man and Machine) project which involves Swerea IVF, Volvo Cars, Volvo Group, Scania and Linköping University. This report address Case 3 of the ToMM project and was conducted at the Volvo GTO plant in Umeå.

The aim of the master thesis was to simulate a Human-Robot Collaboration (HRC) process for the mounting of a cockpit in a Volvo FH truck cab. This was done using the simulation software IPS/IMMA developed by Fraunhofer Chalmers Center. The result of the simulations is a video showing how a collaborative cell may be designed. A possible robot safety system is also presented.

Because of how the assembly is carried out the assembly station cannot fully adhere to the requirements of ISO 10218 - Safety Requirements for Industrial Robots. A risk assessment was made for each stage of the assembly and the station has been designed to as far as possible follow the standard ISO 10218 in order to minimize risks. In addition to the simulation this report contains a literature review of available and for the thesis relevant literature on Human -Robot Collaboration and a brief review of Standard ISO 10218.

The conclusion of the thesis is that if a HRC solution would be implemented employees could be reduced from two to one and total man time from 4 minutes 13 seconds to 2 minutes 20 seconds. The labour cost of cockpit assembly would then be reduced by 1500000 SEK annually. This is based on an annual production of 50 000 cabs.

Sammanfattning

Det här är en rapport om ett examensarbete utförd på institutionen för Industriell Produktion på KTH. Syftet med examensarbetet var att simulera “Human-Robot Collaboration” (HRC) för montering av instrumentbräda i en Volvo FH lastbilshytt. Simuleringarna gjordes i mjukvaran IPS/IMMA framtaget av Fraunhofer Chalmers Center. Resultatet från simuleringarna är en video som visar hur en Human-Robot Collaboration cell kan utformas.

Examensarbetet utfördes vid Volvo GTO Plant in Umeå. Examensarbetet är en del av projektet ToMM - Collaborative Team of Machine and Man som utförs inom ramen för forskningsprogrammet Fordonsstrategisk Forskning och Innovation (FFI). Projektet utförs av Swerea IVF, Volvo Cars, Volvo Group, Scania och Linköpings universitet och detta examensarbete är Case 3 i ToMM-projektet.

På grund av hur monteringen utförs uppfyller monteringsstationen inte de krav som ställs av ISO 10218 - Säkerhetskrav för Industrirobotar. En riskbedömning är gjord för varje moment som ingår i monteringen och monteringsstationen har utformats för att i så stor omfattning som möjligt följa standard ISO 10218 för att minimera risker. Ergonomisk data från simuleringen finns tillgänglig men redovisas inte i denna rapport. Utöver simuleringen innehåller examensarbetet en litteraturstudie över tillgänglig och för examensarbetet relevant litteratur inom Human-Robot Collaboration och en kort genomgång av standard ISO 10218.

Slutsatsen är att om en HRC-lösning skulle implementeras kan antalet medarbetare minskas från två till en och den totala mantiden för monteringen minskas från 4 minuter 13 sekunder till 2 minuter 20 sekunder. Kostnaden för montering av instrumentpanelen skulle därmed minskas med 1 500 000 kronor årligen. Detta baseras på en årlig produktion om 50 000 hytter per år.

Acknowledgement

We would like to thank our supervisor Björn Langbeck for guidance, support, valuable insight and good spirit throughout the writing of this thesis.

We would also like to thank Fredrik Ore at Scania without whose support on IMMA/IPS our master thesis would not have been possible. Thanks to Fraunhofer Chalmers Center for their technical support on IMMA/IPS, and their willingness to help us overcome problems with IMMA IPS. Thanks to Lars O. Olofsson at the Volvo GTO plant in Umeå for being a good host in Umeå and for providing us with help and assistance when needed. Thanks to Lena Moestam at Volvo GTO for being a good host in Gothenburg and for helping us to get started and to understand the Volvo GTO Organization.

Contents

1. Introduction

1.1. Background

This thesis is a part of the Fordonsstrategisk Forskning och Innovation (FFI) project ToMM – Collaborative Team of Man and Machine. Within ToMM this thesis is a part of Work Package 5, Case 3 – Virtual analysis of cab assembly.

The purpose of Human-Robot Collaboration (HRC) is to combine human flexibility with robotic accuracy and strength. The flexibility of human operators and the inflexibility of conventional robot cells limit the use of robots to production lines that are producing large series of a product with few variants. Today robots are more commonly used upstream in a production line, whereas downstream assembly is characterized by a low level of automation. The introduction of Human-Robot Collaboration can increase the use of robots in assembly and in production lines with short lifecycle products and large variations. (Matthias et al. 2011).

Human robot collaboration combines the strength of manual assembly and robot collaboration. HRC provides high flexibility, low variable cost compared to manual assembly and it improves ergonomics for the operator. On one hand, manual assembly is signified by low initial cost, high variable cost and high flexibility. Automation on the other hand has low variable cost, the cost per operation is low, but high initial cost. Another downside of automation is the low flexibility of automated production cells.

The benefits with automation are the cutting of production time and cost per unit. The downside of automation is that automated production cells are inflexible and have a high initial cost for programming. A robot cell also requires a lot of space. These factors make automation suitable for companies that produce large series of products and can afford a high initial cost. It is unsuitable or at least not well implemented in assembly in industries with small product series or large variations in the products.

1.1.1. Benefits of Human-Robot Collaboration

Human-robot Collaboration has the potential to bridge the gap between humans and robots. (Krüger, J., Lien, T. & Verl, A. 2009). HRC can minimize implementation cost, increase availability for SMEs (Small Medium Enterprises), and allow for the use of robots in production of small product series. Human-robot Collaboration systems can also eliminate some of the more hazardous inertia associated with assembly lines. Studies have shown that more than 30% of European industry workers suffer from lower back pain (Krüger et al, 2009) which shows the need for better assembly systems, not just from an efficiency perspective.

The main reason for human-robot collaboration not to be implemented by the industry is the lack of a standards regulating the safety conditions in human-robot collaboration and the difficulty to interpret today's standards relating to acceptable levels of safety. Another problem is the availability of commercial HRC systems. Few models are available and all have a low payload of 10 kg or less.

1.2 Goal

The expected result of this thesis was to design a Human-Robot Collaboration station on a moving line for the assembly of a cockpit in a Volvo FH cab and to present the station as a film simulating this assembly. The cab is a Volvo FH cab and the current state is the operations at the Volvo GTO plant in Umeå. Today the assembly is done with an IAD (Intelligent Assist Device), which eliminates heavy lifting but does not protect the operator from unnecessary torque.

1.3 Purpose

The purpose of the simulations was to understand Human-Robot Collaboration (HRC) conceptually. Since the cost of simulating an industrial process is significantly lower than a full scale implementation virtual models are useful. Human-Robot Collaboration is currently discussed globally, but has not been implemented with heavy robots lifting heavy products. The main reason for the simulations and this project is to visualize what a Human-Robot Collaboration assembly would look like. Such a visualization will also be able to answer a number of questions:

- How can the cell be designed to fulfill current and future safety standards?
- How much does a HRC station reduce lead time at the cockpit assembly?
- Is it possible to reduce the number of workers currently needed?

1.4 Delimitations

There were two types of limitations: initial limitations based on the project description and later limitations that arose due to technical limitations in the simulation software.

The intention of the simulation was to give a conceptual understanding to Human-Robot Collaboration. Safety was secondary and ergonomics was not mentioned at all in the project description. The robot station is designed with the standard ISO 10218 in mind. The intention was not to create a robot cell that fully adheres to a standard, but to create a cell where safety is taken into consideration. Thanks to the software, ergonomic data can be derived from the simulation, but an analysis of ergonomic data was not a part of the project description.

An initial demand from the project description was to have a synchronized movement of the robot and the cab, since the cab is on a moving line. This could not be done due to limitations in the software.

1.5 Methodology

Initially there was a start-up phase where the preliminary goals of the master thesis were defined and where a rough preliminary time plan was created. The different phases of this was learning the software, creating simulations and writing the report. To create a credible simulation there was a need for better understanding of Human-Robot Collaboration and a literary study was needed. A more accurate plan was created with the following phases: Start-Up, Literature review, Data collection, Simulation and Writing the report.

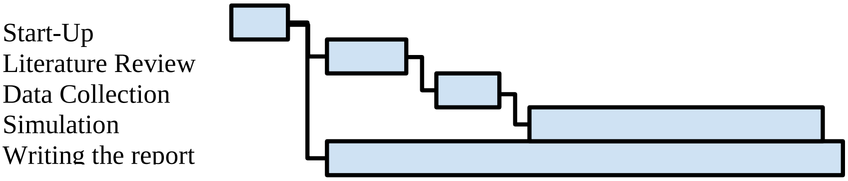

Fig. 1. Time plan.

A literary study was conducted to establish the state of the art in collaborative robotics and to establish the use of collaborative robots in industry today. A study of standard ISO 10218 “Robots and robotic devices - Safety requirements for industrial robots” was conducted to create an understanding of the standard regulating the use of collaborative robots.

A company visit to the Umeå plant was conducted early in the project. The purpose was to get an understanding of how the cockpit/cab assembly is done today and to document the current state of the assembly station. Time was spent observing the work process of the assembly station and videos were shot for documentation.

To get an introduction to the software to be used in the simulations a visit to Gothenburg was made. Another purpose of the visit was to acquire computers powerful enough to carry out the simulations. An invitation to Volvo Cars in Torslanda gave us the opportunity to visit their plant and study their different assembly operations and how car assembly differs from truck assembly.

Before the actual simulations began, the intended future state was created based on data collected from the literary study, the company visits and the standard ISO 10218. A choice of simulation software to be used was made. The choice was based on the ability for the virtual robot to follow the virtual human manikin in the program. The other factor for choosing software was the ability of the simulation to create ergonomic data from the manikin. Once the simulation software was chosen, there was a learning phase to study the chosen software. Once the program was learned, a first series of simulations were created. When the correct virtual models of the cockpit, cab and features of the assembly station were made available the final simulations were created. At a point when simulations were considered finished, video clips were created and subsequently edited. The creation and editing of simulations was an iterative work. Simulations were created and edited until a realistic result was produced.

The report was initiated as soon as the literature study was started. The writing of the report then continued throughout the literary study and simulations. When the literary study and the simulations were finished the report was completed.

2. Literature review

2.1 Literature

The literature covering robot collaboration focuses mostly on smaller robots with a handling capacity of only a few kilograms. The literature found and studied were academic projects involving technology that is not yet being implemented in industry.

Manufacturing industries faces increasing product variety and shorter production cycles which leads to smaller lot sizes and demands higher flexibility than what automated systems are suitable for (Adam and Schultz 2004 as quoted in Busch et al 2009). Most automated systems are found upstream in a production line, where the variations are fewer and the tasks of the production station is repetitive. Manual assembly is more common downstream in a production line, where the variations are many and the assembly tasks more diverse. Human-Robot Collaboration aims at combining the flexibility of human operators and precision and lifting capacity of robots in order to cut manufacturing costs and avoid injuries. With its adaptability to changing assembly tasks HRC has attracted the focus of researchers, manufacturers and robot manufacturers.

2.1.1. Nomenclature and definitions

With the available literature in mind, it is important to differentiate between Human-Robot Collaboration and Human-Robot Interaction. “Interaction is a more general term, including collaboration. Interaction determines action on someone else. It is any kind of action that involves human being or robot, who does not necessarily profit from it. Collaboration means working with someone on something. It aims at reaching a common goal.” (Bauer et al. 2009).

2.1.2. Human Robot Collaboration

Collaborative robots are mechanical devices that provide guidance through the use of servomotors, while a human operator provides motive power. (Krüger et al. 2009). This thesis aims at creating a simulation using an industrial robot as a collaborative robot.

2.1.3. Levels of interaction

Krüger defines Human-Robot Interaction in two types of systems, workplace sharing systems on one hand and workplace and time sharing systems on the other hand. In Workplace sharing systems the interaction is limited to the avoidance of collisions. In workplace and time sharing systems robots and human beings are both working in the same workplace, and both are performing handling tasks in two different configurations:

1. Either the robot is performing an assembly task and the human worker is performing a handling task.
2. Or the robot is performing a handling task and the human worker is performing an assembly task.

Workplace and time sharing systems on the other hand are systems where the human worker and robot are able to jointly perform a handling task or an assembly task at the same time. Krüger et al. (2009) defines four different configurations:

1. The robot is performing an assembly task and the human worker is performing a handling task.
2. The robot is performing a handling task and the human worker is performing an assembly task.
3. The robot and the human worker are jointly performing a handling task,
4. The robot and the human worker are jointly performing an assembly task.

2.1.4. Levels of safety in Human-Robot Collaboration

The safety issue of Human-Robot Collaboration is the major limiting factor for the industrial implementation of HRC systems. The problem is to ensure that a robot does not move undesirably, since the force of a robot easily can hurt the operator if the movement is uncontrolled. Krüger et al. (2009) mentions two levels of HRC safety, Pre-collision systems on one hand and post-collision systems on the other. Pre-collision systems are systems to detect the operator and minimize the risk of collisions. Post-collision systems serve as both control system for the robot and harm reduction.

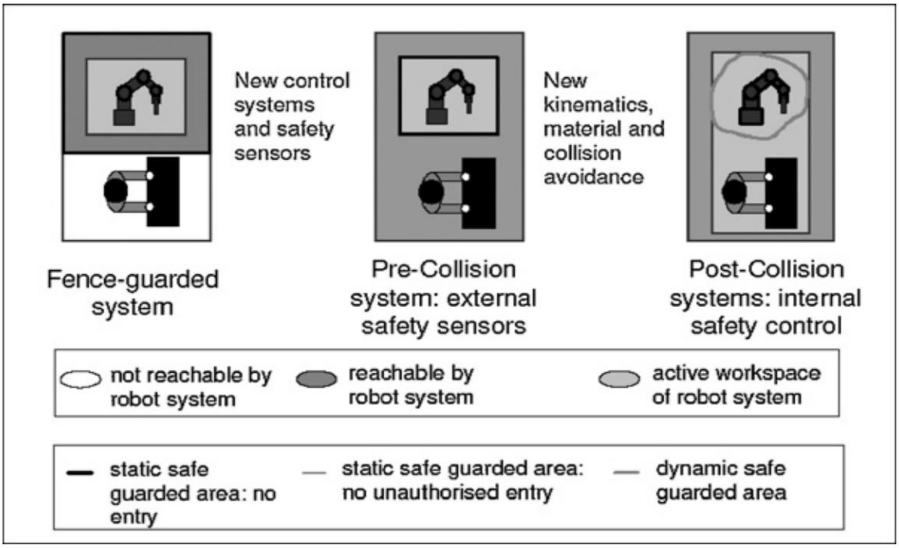

Fig. 2. System graphics safety (Krüger et al. 2009).

A. De Luca and F. Flacco (2012) recognizes four levels of interaction to ensure safe Human-Robot Collaboration. Collision avoidance, physical collision detection and reaction, variable stiffness actuation and lightweight and compliant robots. The three first can be seen as general, while the last one limits the framework to small and lightweight robots. The key to Safe physical Human-Robot Interaction (pHRI) can be conceived as nested layers of consistent behaviors that the robot must guarantee and accomplish.

Schmidt & Wang (2013) mentions vision based approaches such as a single or multiple camera system with emergency stops. They also mention a camera-projector system which creates a dynamic safety zone boundary which can be seen in Fig. 2. The collision detection specific technology discussed in the article is depth image processing with minimum depth calculation. What is important to notice is that all the literature reviewed looks at dynamic boundaries, the closer an operator is to the robot, the slower the robot moves.

One can also divide the Human-Robot Collaboration into three levels of safety related to the physical workspace: Entering/exiting the robot workspace, moving around in the robot workspace and physically interacting with the robot. The first level of safety is entering and exiting the robot workspace or the operating cell. Like any cell the robot needs to find out if there are any operators in the cell and if so, how many? There are a number of systems available to establish this, the technology is the same that is used in conventional robot cell: physical doors with switches, light beams, etc. The second level of safety is moving around in the robot workspace. The third level is physically interacting with the robot.

2.1.4. The difficulties of programming HRC

Programming a collaborative robot for post-collision events can be done with explicit programming using haptics. Haptic programming can be exemplified by two people carrying a big object together and know each other's direction from the applied forces or inertia. (Bauer et al. 2007). In terms of collaborative robots, haptic communication is needed to create a smooth movement. Haptic programming of robots with high force robots are conducted by a number of research groups referred to in Krüger et al. (2009).

Schmidt & Wang (2013) describes pre-collision programming of a HRC cell with a Microsoft Kinect sensor to achieve the dynamic boundary guarded area.

Bauer (2007) describes a general architecture for Human-Robot Collaboration that can be used during all phases, pre-collision and post-collision. The process relies on intention estimation, joint intention, action planning, joint action and learning. "The environment and the partners are observed by sensors. This sensor data is processed to gain an understanding of the environment and provides perception. The perceived data is used firstly to learn and expand the own knowledge, then to gain an understanding of the state of the environment and the partners, and to estimate the intention of the partners. When partners are collaborating, a joint intention is retrieved from the single intentions. A set of actions leading to fulfil the joint intention is found by action planning. At last actions are taken either by single partners or jointly that lead to transitions in the state of the environment. The loop is closed, as the robot observes the actions of itself and of others and the change in the environment.” (Bauer et al. 2007).

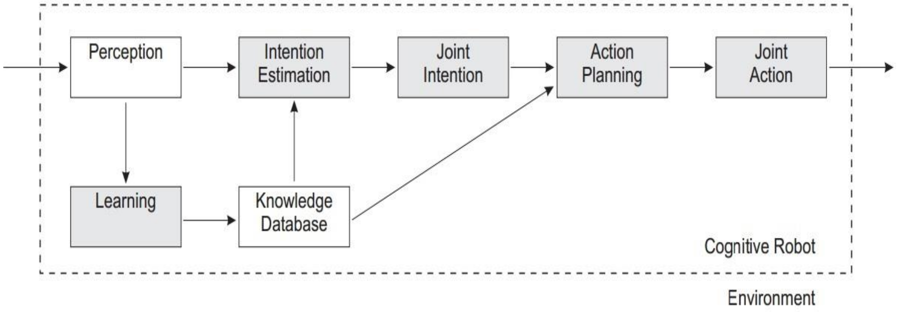

Fig. 3. Bauer’s (2007) architecture of framework for a cognitive robot.

Kosuge et al. (2000) has a functioning code for haptic communication with an operator that was put into real use with the Mobile Robot Helper, where human can carry things together with the Mobile Robot Helper.

Fig. 4. Mobile Robot Helper.

2.1.5. Sensors

In order for a system to determine the operator’s position before physical contact, vision- or IR systems are the most common in academic work, while light beams and physical barriers are more realistic from an industry perspective. A common system within research is a Microsoft Kinect system which is used in Luca & Flacco (2012) among others.

What the robot can do with this sensory input is to slow down its speed or move in a way that avoids collision. Here force-torque sensors can be used (Krüger, 2008) as well as conductive surfaces and IR systems and vision systems. Also in this case, a Kinect sensor can be used (A. De Luca & F. Flacco, 2012) which limits the cost.

Krügers levels	Physical levels	Sensors/ approach/Action	Standard adherence	Source(s).
Pre-collision	Entering/ exiting workspace	Light beams, physical barriers,	Yes	Krüger et al. 2009.
Pre-collision	Moving inside the workspace	Vision systems. Dynamic safety zone.IR-systems Kinect.	No	Luca et al. 2012
Post-collision	Physical interaction	Vision systems. IR-systems Combined: Kinect. Padding, Weaker robots, sensors in axis,	No	Krüger et al. 2009 Bauer et al. 2007

Table. 1. Levels of Interaction.

2.1.6 Ergonomics

Lifting devices relate to 30% of European manufacturing workers suffering from lower back pain. Conventional lifting devices cannot handle inertia, which causes a risk of lower back and spine injuries (Krüger et al, 2009). “Some Manual Handling Devices (MHDs) have been shown to impart significant stress to the back, primarily due to the inertia of the device and load when being dynamically moved” (Chaffin et. al. 1997). Studies conducted can show no decrease in lower back strain as a result of learning how to use a MHD which makes the elimination of torque and stress an important issue in handling and assembly(Chaffin et. al. 1997).

The Institute for Occupational Safety and Health, (2000), states regarding MHDs: “High biomechanical stress on the back can still be a problem, primarily due to the inertia of the device, which produces high acceleration and deceleration phases when utilizing the device”. In further experiments, Chaffin et al. (1999) found that when subjects were instructed and controlled to keep a comfortable speed, material handling devices had a particularly beneficial effect on reducing the compression forces in the lower back during lowering activities.

2.2 Similar installations

HRC installations have been made in the semiconductor industry (Matthias et al. 2011). BMW uses robots from Danish company Universal Robots without physical barriers between the operator and the worker (Knight et al. 2014). This kind of robot operation eliminates the need for physical barriers through weaker robots with built in sensors and soft parts. It works for smaller assembly tasks but is far from collaborative robots. The robots from Universal Robots are also programmable through haptics, the robot is physically guided into position instead of jogged into position with a teach pendant.

Fig. 5. Universal Robots at BMW plant.

2.2.1 Small systems

Many research projects and robot manufacturers are working on smaller robots with collision detection systems. However none of these are for heavy lifting. ABB suggests a cell for handling tasks in the semiconductor industry with their YuMi (Matthias et al., 2011). KUKA Robotics has a robot “LBR iiwa” with built in collision control suitable for the handling of smaller loads. Other manufacturers have similar systems all designed with the mindset “When it hits you it doesn’t hurt”.

2.2.2. Concepts with heavy lifting

Krüger et al. (2009) suggests future use of collaborative robots in aerospace industry, there are at the writing of this thesis no known HRC cells where the operator controls through haptics and the operator and robot carries a heavy load. The project Mobile Robot Helper has the ability to understand intentions of a human while carrying objects (Kosuge 2000). Although its haptic control is successful in lab tests, no haptic interfaces are used in the industry.

2.3 Safety standards

This section is intended as a short introduction to the standards. As opposed to earlier standards the ISO 10218 contains parts relating to collaborative robots. According to ISO 10218, robot collaboration with humans can be described in five types of applications: hand-over window; interface window; collaborative workspace; inspection; and hand-guided robot.

The standard is divided into the requirements on the robot on one hand and the requirements on robot systems and integration on the other. First of all the standard demands an initial risk assessment, where the risks of the robot system are evaluated depending on the type of operations and interaction. To both the robot system and to the robot itself there are a couple of general demands that must apply and additional demands that needs to be adhered to depending on the type of operation. The risk is often dependent on the level of interaction. A hand guided robot demands the following safeguards: Reduced speed, hold-to-run control and a collaborative workspace designed depending on hazards of the application.

2.3.1 Robots

There is one general demand on robots used in collaborative operations and it is that of a visual system indicating that the robot is in collaborative operation. There are 4 additional demands where at least one of them has to be fulfilled. These demands are:

- A safety-rated monitored stop.
- Hand guiding with an emergency stop and an enabling device.
- Speed and separation monitoring.
- Power and force limiting by inherent design or control.

When it comes to hand guided robots, an emergency stop and an enabling device are fundamental.

2.3.2 Robot systems

The requirements on the robot system in its entirety including the robot, is that it is used for predetermined tasks. Secondly, the robot system should only function when all required protective measures are active. Thirdly, only robots with features specifically designed for collaborative assembly should be used. This can mean that conventional robots can be used as long as the features designed for collaboration comply with standard.

The general requirements of the robot system is a risk assessment with 11 requirements, a standard complying robot and presence detection devices to detect people in the workspace. A safeguarding system is demanded to keep a person from going beyond the collaborative workspace, with a perimeter safeguarding. When it comes to hand guided robots, it needs to have a safety stop for the hand-over. An interesting demand of the standard is that the robot system should be installed to provide a minimum clearance of 500 mm from the operating space of the robot (including arm, any attached fixture and the work piece) to areas of building, structures, utilities, other machines and equipment.

3. Our work

3.1 The Volvo GTO Case within ToMM

Currently the cockpit assembly in Umeå is done by two operators. The positioning and fastening of the cockpit is also done by the same two operators. The cockpit weighs about 125 kilograms depending on specifications and is screwed to the front wall of the truck using 42 screws. First, 8 of the screws are attached in a specified sequence to hold the cockpit and then the remaining 34 screws can be attached. The assembly station is on a moving line and the cab moves at 1.5 meters per minute.

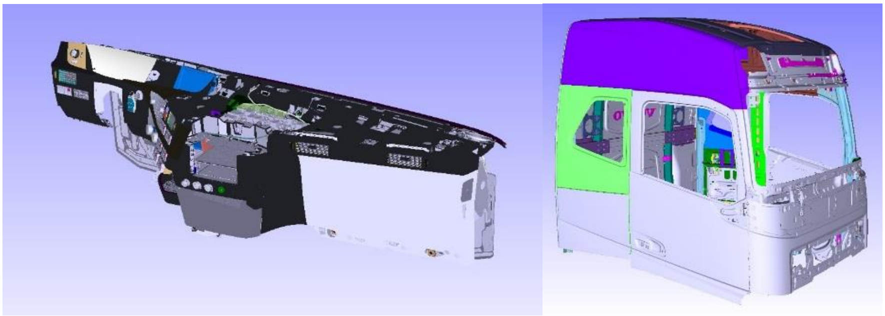

Fig. 6. Picture of cockpit and cab.

3.2 Current state

In the current state, the cockpit is delivered to the station on a carrier. Throughout the assembling of the cockpit two operators are performing the assembly tasks. The time of the operation was measured to 4 minutes and 13 seconds. Today the assembly is done with a semi-motorized lifting device, it is motorized for moving the cockpit up and down but not for eliminating inertia.

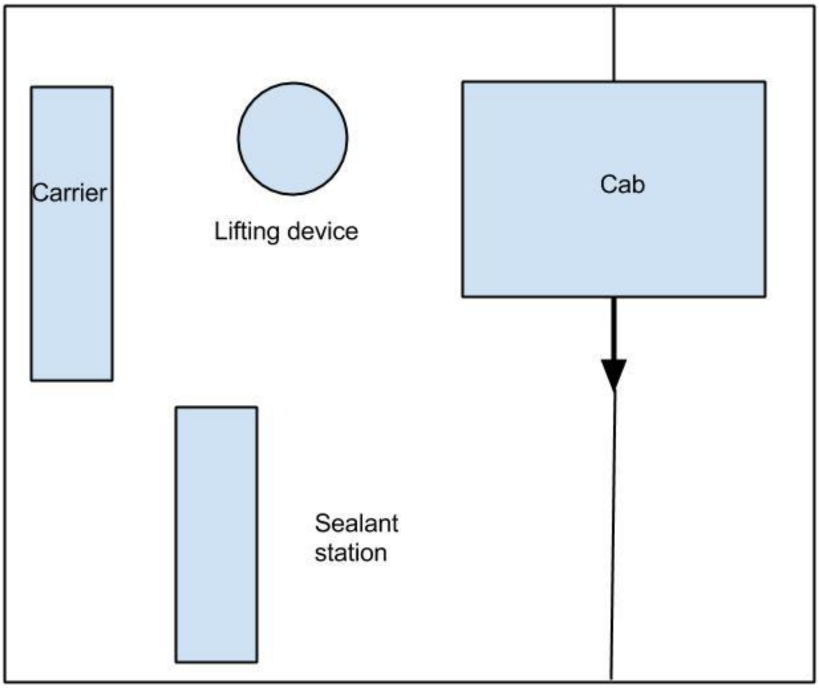

Fig. 8. Current state.

The process is as follows:

1. The cockpit arrives to the station on the line via carrier. The two operators attach the lifting device to the cockpit and lifts it out of the carrier.
2. The operators move the cockpit to a sealant station in where its position is fixed.
3. The two operators manually applies sealant along a pre-made template (see Fig 9 on page 29).
4. The two operators carefully guide the cockpit into the cab. During the moving of the cockpit from the sealant station to the cab the operators need to manage the inertia from the cockpit by hand. There is no motorization horizontally of the lifting device which means that there is no compensation for the inertia of the cockpit and the lifting device.

5. Once the cockpit is in place it is positioned and clamped to the window frame. The two operators attach 8 screws in a predetermined sequence to hold the cockpit.
6. The clamps are released and the lifting device is removed from the cab by one of the operators.
7. The remaining screws are attached by the other operator.

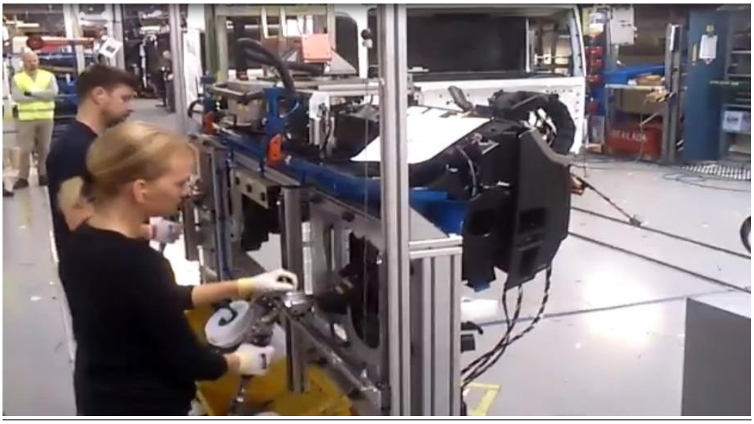

Fig. 9. Operators manually applying sealant at the current sealant station.

3.3 Future State

In the future state the motorized lifting device is replaced by a collaborative robot. The robot used is an ABB 6620. This robot was used because it was the only one available in the chosen simulation software. Further, it had appropriate specifications with a carrying capacity of 150 kilograms which suited our purposes. Because of the tight entry of robot and cockpit into the cab the carrier and sealant station was moved to the left side of the cab since the size of the robot makes entry into the cab from the left side the only available option. In the future state the applying of sealant is automated and the robot is made available for collaborative entry into the cab once sealant is applied. Two sealant stations are used because of the asymmetric pattern in which the sealant is applied. The range of the robot is too short to allow for only one sealant station.

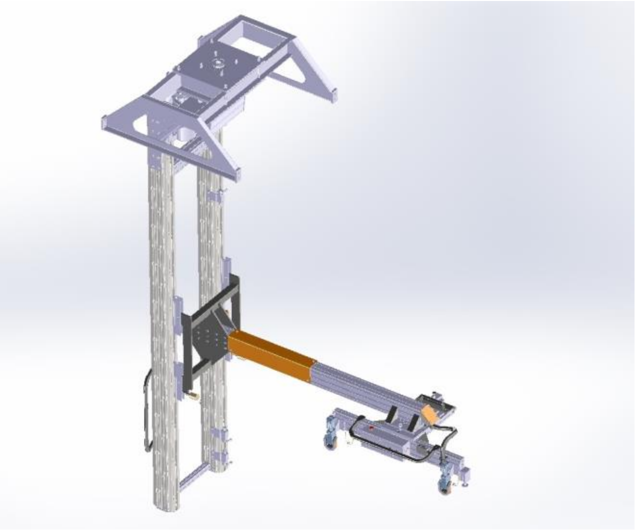

Fig. 7. Current lifting device.

Since a robot cell requires a different level of safety the future state was created with an outer barrier to the cell comprising of physical barriers and light beams to prevent entry into the workspace by unauthorized persons and track the cab. This outer barrier together with individual tags on the operator makes sure that only one operator is inside the cell. By making the space between the cab and the physical barriers too small for a person to enter it becomes hard for an unauthorized person to enter the cell. The light beam in the middle separates the right area (see Fig. 10 below) prohibited for the operator while the robot works autonomously from the left area where the robot has no reach. The suggested safety measures are a result of an iterative process of discussions where input has been provided by both standards and research.

3.3.1 Pre-collision

Light beams can be used for detecting people entering and exiting the cell. If it is a robot like the ones from Universal Robots, only light beams are required. Apart from the above mentioned barriers the pre-collision safety measures can also consist of the type of dynamic safeguarded area mentioned by Krüger et al. (2009).and Luca et al. (2011). The dynamic safety area can be used to vary the speed of the robot depending on the proximity to the operator. By combining a dynamic safeguarded area with individual identification tags on the operator, the system would know the whereabouts and identification of the operator performing moving in the cell. However, dynamic safe-guarded areas are not yet used in the industry, only in academic research. Dynamic safeguarded areas are not implemented because of its components not being approved by robot safety standard.

3.3.2 Post-collision

The post-collision phase described by Krüger et al. (2009) is the phase in which the operator has physical contact with the robot. For this phase to be possible the robot would need the type of architecture mentioned by Bauer et al. (2007) to function collaboratively. The operator would also need an enabling device with an emergency stop as defined in ISO 10218 is for the operator to collaboratively move the cockpit into the cab.

3.3.3. The assembly steps

The assembly of the cockpit can be divided into 9 parts. In the future state the robot is fully automated while applying sealant and in collaborative mode when the cockpit enters the cab and is fastened.

1. The robot picks up the cockpit from the carrier.
2. The cockpit moves to a sealant station where sealant is applied.
3. The robot is made available to the operator.
4. The operator guides the robot and cockpit to and into the cab.
5. The operator presses a button to clamp the gripper to the window frame.
6. The operator attaches the first screws.
7. The operator releases the gripper and guides the robot out of the cab.
8. The robot returns to start position.
9. The operator mounts the remaining screws.

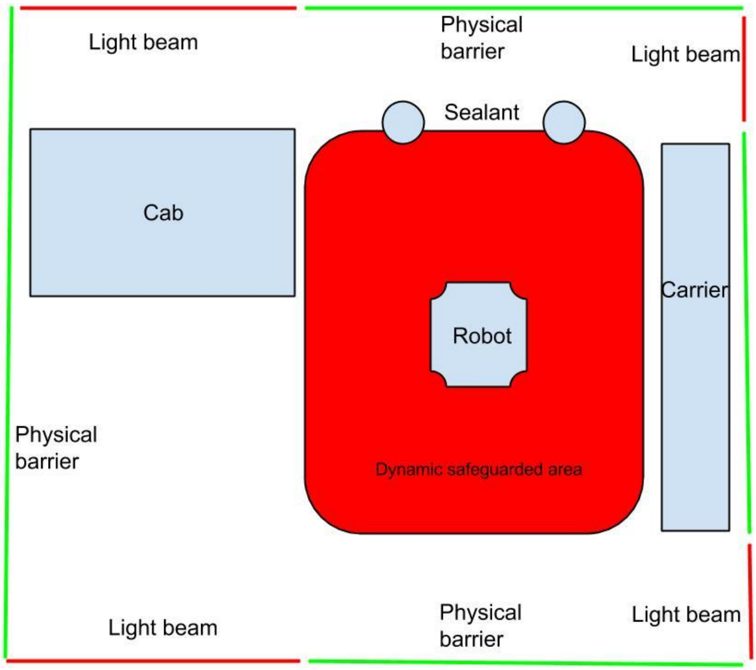

Fig. 10. Layout of new cell (Workshop with Björn Langbeck, 2015)

The robot cell (Step 1 & 2)

The cockpit is presented in a carrier and from there it will be picked up by the robot. The robot takes the cockpit to a sealant application station where sealant is applied. This step is rather straight forward and most of the technique used is common knowledge in terms of a conventional robot station. The pickup position is well defined and the whole operation can be done in a closed area, i.e. all safety issues can be solved in a known way.

The collaborative steps (Steps 3 to 8)

Step 3 - The robot is made available to the operator.

The collaborative assembly begins when the operator approaches the robot. This can be the operator breaking a light beam entering the robot cell or sensors on the robot. Different collision avoidance technologies are described by Schmidt & Wang (2013). To use existing safety equipment light beams can be utilized, since more advanced technology such as a dynamic safeguarded area is not yet available on the market.

Step 4 - The operator guides the robot and cockpit to and into the cab.

This is the first post-collision step. The operator guides the robot into the cab via haptic input.

During this step the robot also needs to sync its speed to the speed of the line on which the cab is placed. The line moves with approximately 1.5 m/min. This synchronization can be done either by code, or physically with a guiding rod attaching the robot to the skid. To avoid collision with the door opening and the interior of the cab during this stage, the robot can be equipped with the kind of combined vision and image processing system that is discussed by Schmidt and Wang (2013). The cockpit is then introduced to the assembly operator who guides it into the cab. This is the novelty with this project. During this last phase (assembly in cab) the robot functions as a collaborative robot i.e. it is physically guided by the operator.

Step 5 - The operator clamps the gripper to the window frame.

The positioning of the cockpit in the cab needs to be very accurate. The gripper clamps to the window frame of the cab to allow the operator to attach the screws necessary for the cockpit to be held in place.

Step 6 - The operator attaches the first screws.

During this phase the robot also needs to move with the line. The robot does not move in any of the six joints.

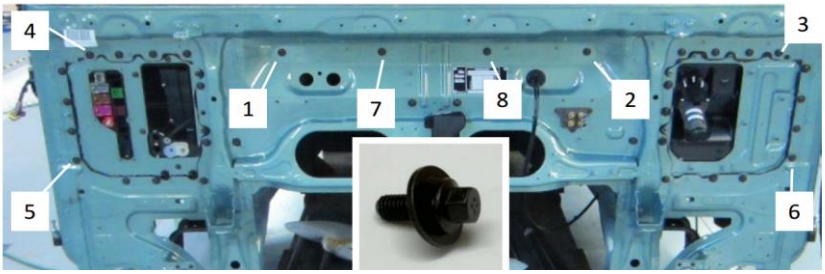

Fig. 11. The sequence in which the first 8 screws are fastened.

Step 7 - The operator releases the gripper and guides the robot out of the cab.

Once the cockpit is in place the gripper is released from the window frame and from the cockpit. It is then guided out of the cockpit.

Step 8 - The robot returns to home

During the steps above the robot has moved in synchronization with the line and now it has to return to its start position. The robot can return to home robot automatically to minimize the non-value adding interaction time of the operator and robot. To avoid damages to the cab, the robot has to be guided out of the cab by the operator and then returned to the cell.

Step 9 - The operator attaches the remaining screws

While the robot returns to home to restart its cycle, the operator attaches the remaining 34 screws and with that the cockpit assembly is finished.

3.4 Simulating Human-Robot Collaboration

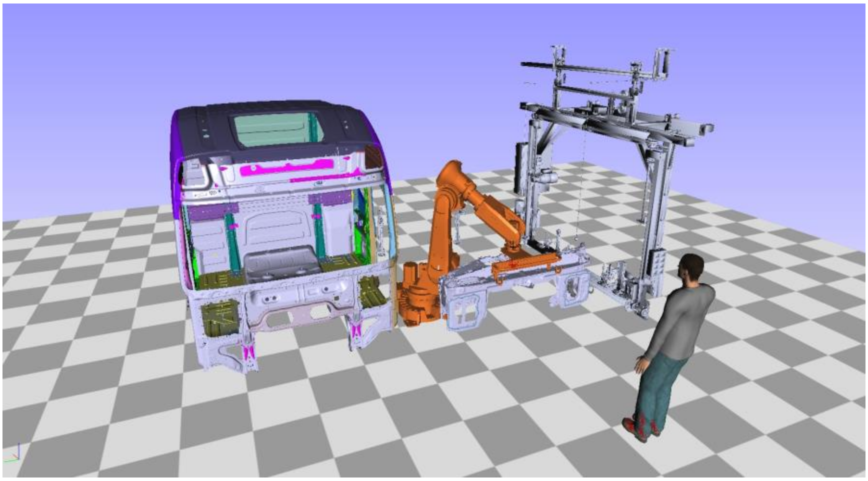

Fig. 12 Station simulated in IMMA/IPS.

3.4.1 The choice of software

At the start of the project there was a choice between two software to use for the simulations. The options where Delmia V4 from Dassault Systemes on one hand and Intelligently Moving Manikins (IMMA) and Industrial Path Solutions (IPS) from Fraunhofer-Chalmers Centre (FCC) in

Gothenburg on the other. The choice fell on IPS/IMMA because it was unclear if it was possible to make a robot and a manikin to follow the cockpit at the same time in the Delmia software. Representatives from Delmia’s helpdesk where uncertain if it was possible and were also uncertain as to what kind of ergonomic data could be extracted which made IPS/IMMA the better choice. With IMMA/IPS we also had help with learning and understanding the program with Fredrik Ore (2014) at Scania.

3.4.2. IPS and IMMA

The IPS software developed by FCC is a math based tool used for the verification of assembly feasibility, design of flexible components (cables and hoses etc.), motion planning and optimization of multi-robot stations and simulation of key surface treatment processes (Industrial Path Solutions, 2014). For this thesis the focus was on the software’s ability to verify assembly feasibility i.e. to generate collision free paths for the assembly of objects. The otherwise time consuming task of manually planning a collision free assembly path is thereby drastically shortened.

The IMMA software is a project currently under development by FCC in cooperation with Volvo GTO, Volvo Cars, Innovatum, Scania CV, Virtual Manufacturing Sweden, Chalmers, Lund University and University of Skövde. The purpose is to develop a combined ergonomics tool and path planner in order to analyze and control biomechanical motions performed by humans during assembly operations. The analysis can be used to minimize the risk of injuries to assembly personnel and also ensure collision free assembly motions for both operators and the objects being assembled (IPS IMMA, 2014-2015).

3.4.3. Factors

There are many factors involved in the choice of concept for process simulation. There were 3 factors which we felt affected the process the most. The first factor is the placement of the robot rail. Should it be on the floor or should it be hanging from an overhead structure? For accessibility it is preferable if it is hanging, but for keeping cost low it can be preferable to mount it on the floor. The second factor is the whereabouts of the operator. Should he or she be inside or outside the cab? The benefit of having an operator outside the cab is that it eases the work of the operator in the sense that he or she does not have to move in and out of cabs, on the other hand, being on the inside of the cab might ease the assembly of the cockpit because of a better overview. The third factor is if there should be one or two operators. One operator is beneficial in an economic context, but two operators can be more secure due to the interaction with the robot. This gives in total 8 options for the simulation, but since there is only one operator handling the cockpit inside the cab only two first factors needs to be considered which results in 4 different scenarios and 4 different simulations.

- Floor mounted robot with operator outside the cab.
- Floor mounted robot with operator inside the cab.
- Ceiling mounted robot with operator outside the cab.
- Ceiling mounted robot with operator inside the cab.

The choice to keep the operator outside the cab was made to minimize the risk of squeezing accidents between the operator and the cab. The choice to put the robot on the floor was made because the software IPS/IMMA did not support solutions with the robot put in the ceiling. The robot is also impossible to put in the ceiling due to range problems. If the robot was to be put in a hanging position, the cockpit would not reach its final position without the robot hitting the door opening of the cab.

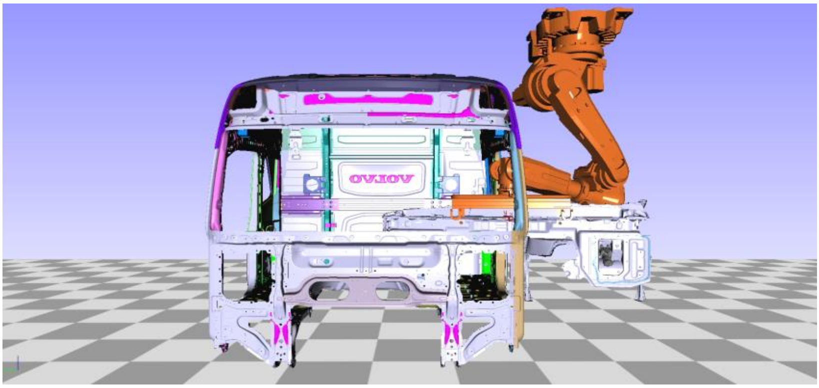

Fig. 13. Picture from IPS with robot in the ceiling.

3.4.4. Simulation Working Process

When working with simulations in IMMA, one of the more important components are paths. Paths are created in IPS 1.4 and are a way of moving objects from one point to another without colliding with other objects present. An object can be anything from a very simple shape to something much more complex as long as it is reasonably sized (in MB) and in the correct format (vrml). The paths are computer generated and consist of a number of points. It is possible to make adjustments (x, y, z and rotational) to every point and in that way customize the path to specific needs. It is also possible to order the path generator to e.g. give preference to rotational movement instead of translation.

To create a path an object is selected and then assigned the desired start/goal positions. A path can then be generated. If the generated path is considered satisfactory it may be saved. If it is not, a new path may be created with different preferences. Since there is no possibility to use a robot manikin in IPS 1.4 every path has to be evaluated in IMMA. For example, a path created in IPS 1.4 may not be applicable to a robot in IMMA since IPS 1.4 does not take robot reach or even the existence of a robot at all into consideration.

The latter also implies that collision between the robot itself and the object moving along the path is ignored. This type of collision must be examined manually in IMMA. After evaluation in IMMA adjustments are made in IPS 1.4 and the path is then exported back to IMMA for a new evaluation. This iterative process will then be repeated a number of times until the desired path has been produced.

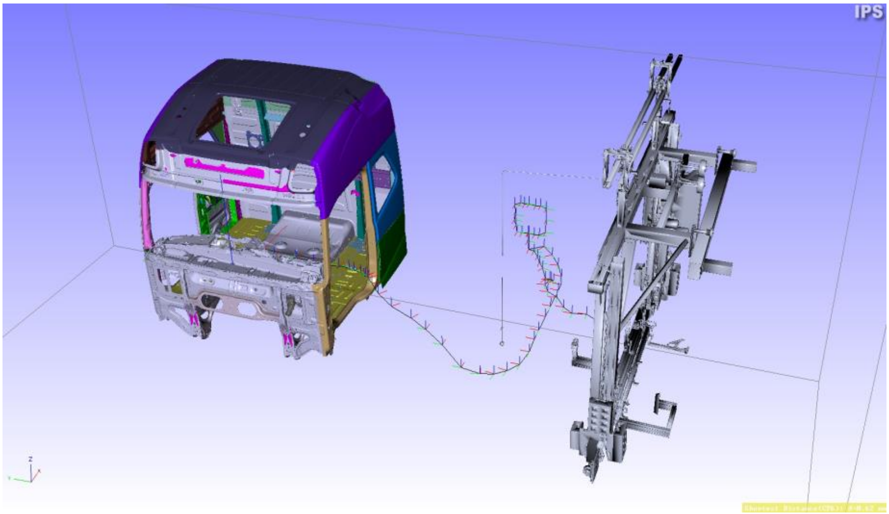

Fig. 14. Models and paths in IPS 1.4.

The actual simulations are made in IMMA. All of the models (in .wrl format) needed are imported into the IMMA scene and placed in the desired positions. The paths generated in IPS 1.4 are then imported and finally the robot and manikin. The standard robot in IMMA (ABB 6620) comes without any tools so in our case a customized gripper based on Volvo's existing lifting tool was created using CAD software (SolidWorks). When all objects and paths have been imported the task of creating grip points begins. A grip point is a point on an object where a robot/manikin will grasp when an object moves along a path. For a robot, the grip point can be adjusted for x, y, z and rotation. This is also the case for manikin grip points with the addition of the possibility of choosing the specific grasping type (cylindrical grip, spherical grip, pistol grip etc.).

In its simplest form this is what is needed to simulate a movement, a robot/manikin grasping a grip point on an object which is assigned to a path. An important distinction here is that it is not the robot/manikin that is moving the object. The robot/manikin is merely following the objects movement along the path gripping the grip points. This is important to understand if an adjustment to, for example, the robot movement needs to be made. The only way to make such an adjustment is to modify the path in question.

For every simulation it is only possible to choose one family (i.e. a robot or a manikin), one path and one object. This means that only one object movement can be simulated at a time. This also means that having the cab move along a line and simultaneously move the cockpit is not possible. At least not in the current version of IMMA. This was one of the initial goals of the ToMM project description. The fact that it was not possible is unfortunate. However, even if it would be possible the cab and the robot does not move in relation to each other making our simulations with static components nearly identical. Further, the speed of the line (1.5 m/min) would make the movement barely perceivable in any simulation.

The IMMA software is not developed specifically for Human-Robot Collaboration. This implies that any simulation involving a manikin and robot can only be performed by using software functions not particularly designed for this purpose. As a result of this the collaborative parts of the simulations have to be performed separately making it impossible to have a continuous simulation sequence. To tackle this problem video clips recorded in IMMA from the different simulations can be put together to create a film with any editing software. Further, this means that ergonomic data from a HRC sequence is unavailable. However, since (as explained above) both robot and manikin follow the objects way along a path the manikin will (given that the same path is used) behave identically when the robot is excluded from the simulation. Ergonomic data for the different sequences is thus available albeit without incorporating any robot movement.

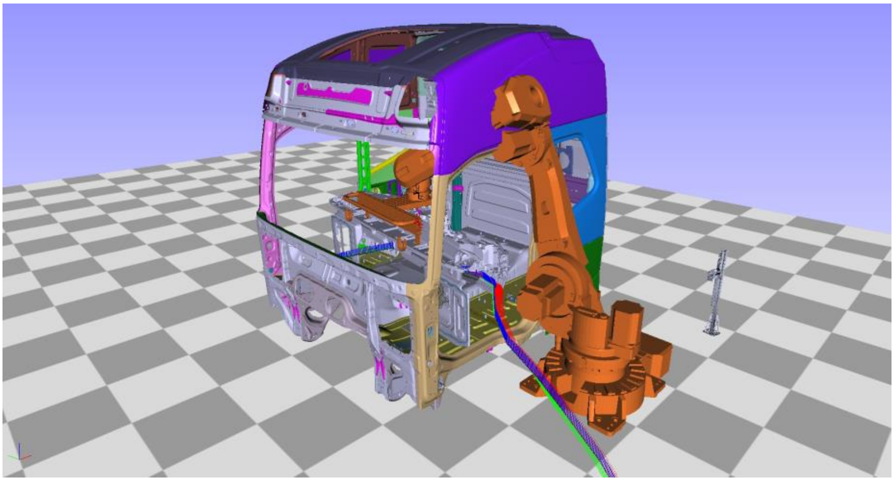

Fig. 15. Robot colliding with cab.

Another issue when simulating in IMMA is that, as opposed to the object (the cockpit in our case), the robot movement is not collision free. For example, by creating a path in IPS 1.4 we have a guaranteed collision free path for the cockpit from outside the cab to the position of assembly inside. However, when following the collision free path of the cockpit the robot may well collide with any part of the cab or the cockpit. The collision free path only considers the cab and the cockpit, not the robot. This means that a time consuming manual iterative work has to be done examining every single frame of the simulation making sure that the robot does not collide with any other components. If a collision is detected either the placement of the robot, the configuration of the path or both have to be adjusted. After adjustment the procedure is repeated until both object and robot are collision free.

3.4.5. Problems simulating

Two different formats can be used in the IPS/IMMA software. Either Jupiter (.jt) or VRML (.wrl). This was a problem because Volvo does not themselves use these formats for CAD models. Since there was a need to get immediate experience of working with the software the decision was made to create simple CAD models, mock-ups, of the most important components (Fig 15). At the early stages of the simulations these proved to be excellent substitutes since this period was a software learning process and exact dimensions were not necessary. The simulations created and the knowledge gathered during this time would show to be of high value later in the project.

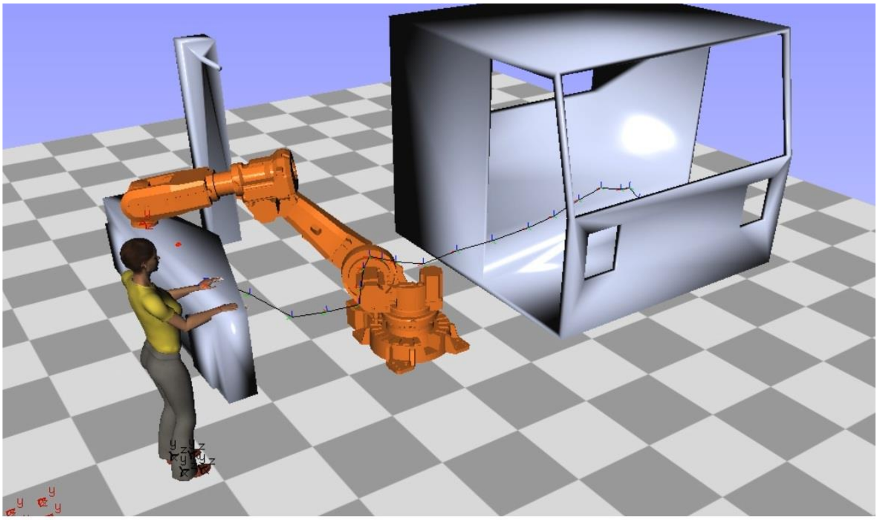

Fig. 16. Screenshot from early simulations.

When access eventually was gained to CAD models in the correct format another problem arose. The size of the CAD-files required a long process time. A Volvo CAD file of the cab in the Catia Graphical Representation format (.cgr) with a size of 1.26 GB would increase to 5.4 GB when converted into VRML. A CAD file of this dimension is impossible to import into the IPS/IMMA software and subsequently had to be reduced in size. This was done by importing the models into CAD software (SolidWorks) and then removing parts that were of no or little relevance to our simulations. In the case of the cab, the file received was a complete cab with many parts (doors and front parts etc.) that had to be removed to resemble its state at the cockpit assembly station. Additional parts of no relevance were also removed to further reduce size for the CAD model to work in the simulation software. The cab is supposed to be stationary throughout the simulation and is therefore less size sensitive than the moving part, the cockpit. To make simulations smooth and time efficient the cockpit was stripped of all parts not deemed absolutely necessary (Fig. 17). The same procedure was repeated with the remaining objects (carrier, gripper and sealant applicator). When all components had been reduced to manageable size the work of putting together the simulation could begin.

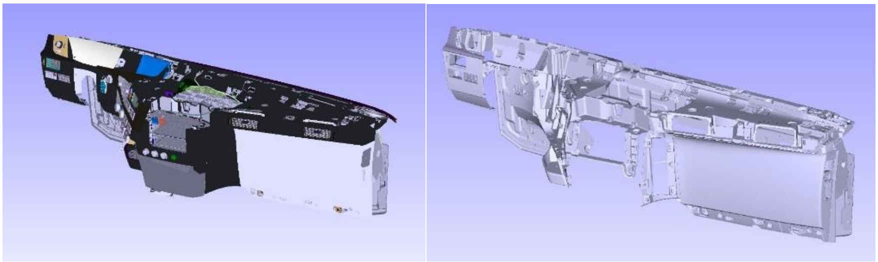

Fig. 17. The cockpit before and after size reduction.

As mentioned before the IMMA software is currently under development and as with all such software problems are bound to arise. During the project we have received a number of updates to solve certain issues but still the software has proven to be somewhat unreliable. Crashes can occur systematically when performing specific operations or at random. The systematical crashes can be avoided by trying to find other ways of performing a task but the random crashes are by nature hard to predict. The way to mitigate the damages of these crashes is simply to save your work frequently. When starting up, the crashes were a major issue as they were slowing down the work and really testing our patience. As our work moved along we learned to avoid the operations we knew were crash-prone and therefore reduced the problem to a manageable level.

3.4.7. The making of the film

Since a single sequence of the simulation proved to be impossible the film created is composed of a total of 13 different clips. These clips have then been edited together to form a continuous simulation sequence. The non-collaborative parts could theoretically have been a single clip but to be able to show different angles to highlight particular operations the choice was made to divide these as well. The result is a video showing all operations from appropriate angles.

For the sealant application sequence the speed used is a result of information gathered from Volvo Cars. They use a speed of 150 mm/s for robot application of sealant. This combined with an estimation of the distance that should be processed gave us a time of roughly 11 s per side. For time estimation of the screw fastening sequence the video shot at the Umeå plant was used as reference. From this the time to fasten 8 screws was determined to about 20 s. The speed of the remaining non-collaborative parts (robot only movement) are based on the fragility of the cockpit and safety considerations and are pure estimates. The collaborative parts of the sequence are also estimations due to the fact that different operators work at different speed etc.

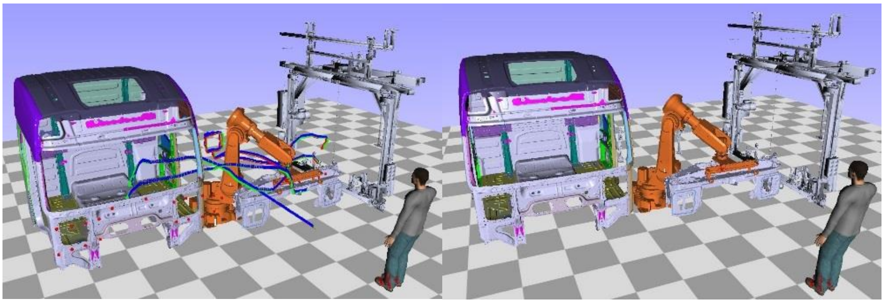

Fig. 18. The final IMMA scene with and without paths.

3.4.6. Results from simulations

Our simulations show that it is possible to guide the cockpit into place in the FH cab using HRC. However, when guiding the cockpit through the door opening it is in some places a very tight fit. Tighter than the 500 mm stipulated by the standard ISO 10218. A different robot may provide better reach and more maneuverability but since the software limits the choice of robot to the ABB 6620 this has not been investigated. As a result of the tight fit the focus has been on creating a collision free path for the cockpit to follow when entering the cockpit. The ergonomics has thus been regarded as a secondary issue. While the simulation shows it is possible for an operator to guide the cockpit into place it is not optimal from an ergonomic standpoint.

Another result of the simulations is that the number of operators can be reduced from two to one. Several operations that are currently performed manually can be automated thereby providing the operator time to perform other tasks e.g. fastening remaining screws. This also indicates that since work is performed in parallel, lead time can be reduced. From the lead times obtained from the film we were able to determine the reduction of variable cost with a collaborative cell instead of the current. An estimated labour cost for a worker in Swedish industry is 300 SEK/h. This gives a cost per minute of 5 SEK. With such a figure the cost of the current assembly with 2 workers and a total assembly time 4 minutes 13 seconds is:

$$5 \times 4.22 \times 2 \approx 42\, SEK$$

With the collaborative cell, only one operator is required and the cycle time is estimated to 2 minutes and 20 seconds.

$$5 \times 2.33 \approx 12\, SEK$$

This gives a total reduction of variable cost of 30 SEK per mounted cockpit. At an estimated 50.000 cabs produced each year this would result in:

$$50000 \times 30 = 1500000\, SEK$$

It should be said that since robot and manikin speeds are estimations the times and sums above are indicative.

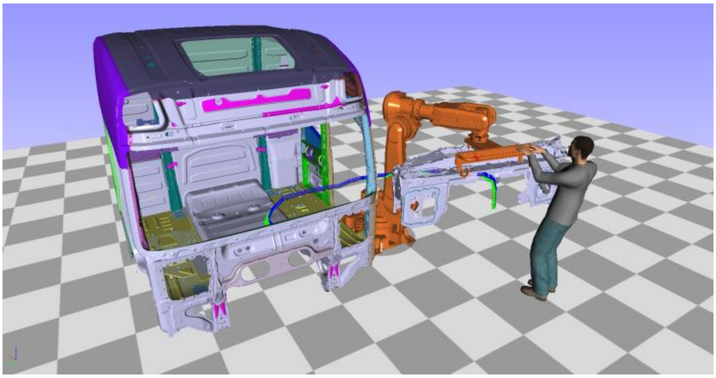

Fig. 19. The station.

4. Adapting to current safety standards

If the cell was to be designed for HRC, it would be easier to have the cell takted and not on a moving line since the robot needs to move alongside the line if the line is moving. Such a synchronization adds unnecessary risk and cost. The standard ISO 10218 stipulates the need of an enabling device and the options were either a space mouse or a force torque sensor. The benefit of a force-torque sensor is that it is attached to the robot and makes the handling of the robot more intuitive. We decided that the simplest way was to have an enabling device that was a combination of a “kill-switch” and a force-torque sensor. One of the major obstacles for the process to adhere to standard is that ISO 10218 stipulates a minimum distance to edges where there is a risk for pinching of 500 mm. This is a problem when the cockpit enters the cab.

4.1. Risk Modes

There are many risk modes during the cockpit assembly. We based our risk assessment on the levels of safety displayed in table 2 (page 47): entering the station, moving inside the station and physically interacting with the robot. The outer barriers consisting of light beams and physical barriers are needed to track the operator entering the station, and ensures that no unauthorized person enter. The combination of outer barriers, a dynamic safeguarded area, an enabling device and personal identification tags are all safety measures to reduce risk.

4.1.1. Entering the station

There is a constant risk of unauthorized persons entering or exiting the station and the working zone of the robot and the operator and thereby getting hit by the robot. This can be avoided by having the entire cell surrounded by sensors so that every operator that enters the zone is monitored. It can also be achieved with the dynamic boundary safe area described by Krüger et al (2009) and by Luca et al. (2012). The outer edge of the station consisting of physical barriers and light beams will then detect all persons entering the station with one exception. An unauthorized person can enter the cab before the cab enters the station. This is precarious since the only way out of the cab is into a very close proximity of the robot. This risk can be managed by the dynamic safety zone.

4.1.2. Pre-collision / Moving inside the station

During the first steps of the cycle the robot works autonomously which means that all risks during the automated cycle can be handled with existing technology and in a way that adheres to standard. The first risk associated with a collaborative workflow is when the operator comes close to the robot. This risk can be managed with a vision system with depth image calculation (Luca &. Flacco 2012).

4.1.3. Post-collision / Contact phase

During step 4 as the operator guides the robot from the cell to the cab, the biggest risk is that of crushing injuries. Since the robot is completely controlled through haptic input from the operator, injuries may come from human error. Even if the robot control system is robust, an unskilled operator can crash the robot into the cab or himself or get trapped between different joints of the robot or the robot and the cab. One way of avoiding this type of damage is to combine the haptic input with the type of vision system discussed by Luca et al. (2012) which would make the robot stop if an imminent collision was detected. The hard part with this is to distinguish the operator from the surroundings in the image-processing.

The problem of collision also occurs in step 5 as the operator guides the cockpit and robot into the cab. The door opening is very narrow for the robot, and a vision system to detect collision would reduce risk immensely. During this step it would also be easier for the robot to distinguish the cab from the operator since the operator is mostly outside the door opening. While entering the cab the risk is for the hands of the operator to get squeezed, and for the robot and/or cockpit to hit the cab exterior and interior or the door frame.

During step 7 while exiting the cab there is again the risk of the robot colliding with the cab interior or the door opening. Once the robot is out of the cab the main risk is for the robot to hit or squeeze the operator.

Krügers levels	Physical levels	Risk	Sensors/ approach/Action
Pre-collision	Entering/ exiting station	Unauthorized station entry	Light beam, physical barriers
Pre-collision	Moving inside the station	Collision with robot	Vision systems. Dynamic safety zone.IR-systems Kinect.
Post-collision	Physical interaction with the robot	Squeezing, Collision with cab	Vision systems. IR-systems Combined: Kinect. Padding, Weaker robots, sensors in axis,

Table 2. Krügers levels and risk

5. Human-Robot Collaboration with heavy components

As mentioned earlier, most of the research on collaborative robots is done with smaller robots and smaller loads. Many post-collision systems are based on the idea “If you hit me it doesn’t hurt”. The outcome on the robot market is that collaborative robots, such as ABB’s YuMi or KUKAs LBR iiwa, are fitted with sensors and/or soft padding. When it comes to larger robots handling larger loads, such robots are not in existence yet. This can most likely be attributed to the lack of working standards as mentioned above. It should be possible to have the same approach to larger robots.

5.1. Pre-collision

The pre-collision for a large and powerful collaborative robot is the same as that of a smaller one. The one thing that needs to be addressed is how sudden movements and stops affect the part the robot is carrying? Large components can be more sensitive to stops than smaller ones. This does not however affect the architecture of handling the problem nor does it affect the input sensors. The only thing that changes is the possible top speed and the possible change of speed, the time to slow down the robot or the time to put the robot to a complete stop. The derivative of the speed decrease cannot be as steep when handling large components.

5.2. Post-collision

A problem with hand guided robots is the system should be designed to ensure a safe environment. This is particularly important regarding large robots. A way of control is suggested by Krüger et al. (2008) which ensures robustness from the system. A similar system can also be found in the Mobile Robot Helper (Kosuge et al. 2000). There is also a safety issue relating to the sensitivity of the force sensor. If the robot is carrying a weight of 300 kg the force of a finger or a hand trapped between the robot and a sharp edge needs to be noticed. A way to manage this type of risk would be to fit larger robots with the same kind of pressure sensitive sensors as the smaller collaborative robots are fitted with.

5.3. Sensor Sensitivity - Heavy load and light input

The way by which the interface is designed depends on the sensitivity of available force-torque sensors. The sensors need to be able to distinguish an operators haptic input from the load of the carried component. If the robot is carrying a weight of 300 kg the force the operator puts on the handle and robot needs to be enough to guide the robot with satisfactory precision. The force from the operator also needs to be small to avoid unnecessary strain on the operator. If the sensitivity of the force sensors are not enough, a space mouse or other interface is necessary for the operator to give input data to the robot. If the sensor in itself is sensitive enough it should only need to be coupled with an emergency release handle being the enabling device demanded by ISO 10218 to function collaboratively.

The technology of using a force-torque sensor to enable the operator to move the robot is described by Krüger et al (2009) but there the heavy handling is separated from the human interaction. The robot first conducts the heavy lifting, then the interaction with the operator comes. The difference, and the challenge lies in creating a system that is sensitive to the force and inertia input from the operator while carrying a heavy load.

6. Evaluation of the project

As mentioned earlier in this report there are some issues with the software. However, this is only what can be expected when working with software that is under development. During this project we have had several updates to both the IMMA and IPS software which have eliminated particular or general problems. We have also been able to have first-hand contact with the developers at FCC who have been quite helpful. This contact has led us to understand that many of the limitations we have experienced will be addressed in future versions.

Since we had no access to the software for the first months of the project we had time to envision the steps of the intended simulation and do a risk analysis of the individual steps and how these risks could be managed. We also had time to discuss whether or not these solutions were in compliance with standard ISO 10218.

In retrospect, it was good to define the cell to be simulated prior to the simulations were made since it gave a sense of feasibility, to have a sense of reality in the simulations. It was also good to have a clear view of our imagined future state before we started to make simulations. It gave us a good understanding of the realities and problems related to adhering to industry standards.

6.1. Literature review

The literature review focused on academic papers and the academic frontier of Human-Robot Collaboration. If we were to have done it again, the focus had been more on implementation than on what research groups are studying. It is easy to focus too hard on what is new and innovative than to focus on what works and what is tested.

6.2. Choice of software

In the beginning of the project we chose between using Delmia V4 or the IMMA and IPS programs supplied by Fraunhofer Chalmers. This choice, as all choices was made with many factors unknown. None of us had any previous experience from simulations which led to a decision made on input from sales representatives, help desks and advice from more experienced users involved in the ToMM project. If we would have remade the choice of software from the start - it should have been more thorough and systematic perhaps with some sort of score card with listed strengths and weaknesses of each software and grading to represent the importance of each of these strengths and/or features. In essence, a more structured analysis of the two available software.

6.3. Safety

One obstacle discussed for a long time was the need for an enabling device. Since the standard demands an enabling device we discussed this back and forth for a long time. The choice to use a CAD-model with just a simple handle with a “Kill-switch” was made on the assumption that such a device would be enough to fulfil standard ISO 10218 demands for an enabling device. The safety issue in general was discussed often since it is what can make the simulated cell realistic.

6.4. Structure

A very general conclusion of this thesis is that the writing of a report is a good process in itself to define and structure knowledge. To keep better track of the project we could have had more short term goals. Almost all projects change along the way, and the project plan can be made more detailed than what we had. If more short term goals would have been created it would have been easier to keep track of the progress of the work on a weekly or daily basis. However, we realized it is difficult to establish short term goals when dealing with work that involves a lot of learning. Estimations of the time required for certain tasks and subtasks tend to be very rough. As we came closer to finishing the report, and when work slowed down, short term goals were created to speed up the process and to get an overview of what was left.

7. Future suggestions - Focus for Volvo GTO

Human-Robot Collaboration will most likely play a larger role in assembly in the future. Since collaborative robots have the ability to cut cost in assembly, the use of collaborative robots will increase. Likewise the use of simulation software will increase since simulation cuts cost and saves time when planning new production lines and new stations along those lines.

7.1. Human-Robot Collaboration

The development so far is led mostly by the academic world and by robot suppliers. As more collaborative robots are developed and put to use in the industry, the HRC research within industry will increase. As the technology matures, when risks are satisfactory managed, larger collaborative robots carrying heavier loads will be the focus of research.

7.1.1. Haptics and Safety

Haptics will most likely be the focus among robot suppliers and the academic world. Safety is today discussed by robot suppliers, academia, industry and within the standard. The different sensors and safety measures that are being developed at academic institutions use technology from the video game industry. In the future this technology will most likely shift to industrial grade sensors adhering to standards thus making the development of safety systems shift more toward robot suppliers and other suppliers. The focus on safety within HRC will continue to be an important research topic, and most likely more important as the technologies developed today are standardized.

7.1.2. Structured Implementation of HRC

Implementation will be the focus within the industry. Since few collaborative robots are used within the industry today there will be a need for future assessments and frameworks for a company like Volvo GTO to determine when a HRC system can and should be implemented.

7.2. Simulations

Simulating production lines in terms of both efficiency and ergonomics is important today and will be more important in the future since it cuts cost and reduces risk of injury. We think that Volvo GTO should systematically evaluate their need of simulation and with that as background evaluate all simulation software available today.

7.2.1. Develop Software

Another issue that Volvo GTO already is addressing is what they can do to further develop software. Thanks to Volvo’s cooperation with Fraunhofer-Chalmers Center on IPS/IMMA, Volvo are able to put their needs, if well defined, into the specifications on the IPS/IMMA software.

We also think that SWEREA should put the focus of future research in relation to future standards in terms of what is possible and what is allowed. The technologies used in research today rely heavily on technology that is not approved by the industry with the Microsoft Kinect being one example. Future focus of research at SWEREA should be put on systems that integrate technology made to comply with industry standard. If a project is not possible due to current standards then at least the project should be evaluated to adhere to possible future standards which we tried to do with this project.

8. Sources

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Appendix 1. Project Description

Master thesis simulation of co-operation man and robot when assembling cockpits in truck cabs – Volvo GTO

Within the research project ToMM (Team of Man and Machine) industry, university and institute work together investigating new possibilities for using robots as a helping tool for the assembly worker. The companies are Volvo Cars, Volvo GTO and Scania. The researchers are Swerea IVF and Linköping University.

Each company has brought one case into the project. Volvo GTO has chosen assembly of the cockpit into the truck cab. This is a challenging case and fro in-depth studies it has been decided to simulate the whole assembly.

The cockpit is presented in a carrier and from there it shall be picked by a robot. The robot takes the cockpit to a sealing station where sealant is applied in two places. This step is rather straight forward and most of the technique used is common knowledge. The pick-up place is well defined and the whole operation can be done in a closed area, i.e. all safety issues can be solved in a known way.

Sealant application is done manually today.

The cockpit is then introduced to the assembly worker who is guiding it into the cab. This is the novelty with this project. During this last phase (assembly in cab) the robot is works as a lifting device; it is guided by the worker. This means that the worker is holding in the cockpit and the robot follows the movement he is doing.

There are several issues that are to be answered by the simulation. How can the robot motion be synchronized with the line motion? Is there enough space for the operator to guide the cockpit through the door or does two workers have to co-operate (one inside the cab and one outside)? Can the robot move the cockpit through the door autonomously and introduce it to the operator inside the cab? These are examples of questions. During the project some new might come up yet some might be seen not relevant.

Today’s lifting device for assembly in the cab.

Due to the questions above it is obvious that the simulation must include the workers. The manikin from the IMMA-project will be used for this. The work will be done using existing software from Dassault and Delmia. The cab is designed in Catia V5. The cab assembly line is a continuously moving (approx. 1.5 m/min) and the robot must be synchronized with that. There are two possibilities for the robot placement, on a floor based track or on a track hanging from above. Both these should be simulated. The work may include some design of tooling. Expertise in this area is supported by Volvo GTO. Expertise regarding the ToMM project, ideas and result from it will be supported by Swerea IVF and Volvo GTO together.

The safety issues are of outmost importance when introducing this kind of assembly aid, but that will not be a part of this work. In the virtual world it is enough to pursue that these issues are solved.

The work can start very soon and it is intended to be done at KTH in Stockholm. Naturally some visits to the Umeå plant are necessary.

The work is initiated and financed by Volvo GTO.

The final report as well as reporting during the project is to be done in English. Working language during the project is English or Swedish.

Supervisors for the project

At Volvo GTO in Umeå Lars Olofsson, production engineer, expert in assembly tooling; lars.o.olofsson@volvo.com

At Swerea IVF in Stockholm Björn Langbeck, assembly expert and project manager; bjorn.langbeck@swerea.se

About Volvo GTO

GTO is the truck industrial entity within the Volvo Group responsible for Truck manufacturing, including Cab & Vehicle Assembly, Powertrain Production, Logistics Services, Parts Distribution and Remanufacturing. Group Trucks Operations manufacture state-of-the-art products for the brands of the Volvo Group.

In 2013 almost 200,000 trucks were delivered from the facilities to the different markets. Group Trucks Operations has a global industrial footprint that offers an opportunity to an international world class industrial environment, where continuous improvement and productivity improvement is driven through Volvo Production System (VPS).

There are 45 plants and 54 distribution centers in total. The organization includes approximately 34,000 employees in 36 countries.

The Umeå plant

In Umeå all cabs for the European production are produced. The cabs are delivered to the final assembly plants in Gent (Belgium), Gothenburg and Kaluga (Russia). Some cabs are delivered as body-in-white and the final trim (assembly) is done at the final assembly plant. Today all cabs for Gothenburg and Kaluga are trimmed in Umeå but this will be moved to Gothenburg.

The product range for trimmed cabs is the Volvo FH and Volvo FM (and some special variants).

Also kits are packed and delivered to CKD-plants around the world. (CKD=completely knocked down, the truck is delivered in a kit and assembly is done in a small plant close to the final customer.)