Optimizing Welding Cycle with the Utilization of the IPS Tool

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Preface

This thesis covers the criteria to complete a Master of Science degree in Mechanical Engineering at Luleå Tekniska Universitet. This project was performed at Scania CV AB in Södertälje within a smaller branch of SPS & Industrial development called TDE. The thesis was conducted within the period of October 2012 and April 2013 with the supervision of Torbjörn Ilar at the Department of Engineering Science and mathematics.

Thereby I would like to thank my supervisor at Scania, Lars Hanson, for giving me the opportunity to conduct this thesis as well as the support and guidance throughout the whole project. I also want to thank Daniel Segerdahl at FCC for providing me with the software and all the updates made specifically for this project not to mention all the guidance on the usage of the software. I also want to give my gratitude to the people at Scania in Oskarshamn who provided me with all the information vital for this project and all the personnel at TDE who provided me with consistent help throughout the thesis. At Luleå Tekniska Universitet I would like to thank my supervisor, Torbjörn Ilar, for the guidance on the layout and structure of the thesis report.

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Abstract

A car body is one of the most significant part of a vehicle; known as Body-in-White, BiW, it impacts characteristics such as top speed, fuel consumption, safety and handling. In today’s industry most of the path planning is performed manually instead of automated offline programming, thus consuming more time and eliminates the opportunity of finding the most optimized path. A typical BiW consist of approximately 300 sheet metal parts that is joined by around 4000 weld spots. BiWs are usually pre-assembled into under-body, body sides, roof and body closures separately before assembled into a complete BiW. Therefore all the weld spots have to be distributed amongst a number of robots. The weld spots have to be distributed equally amongst every robot cells as well as robots to gain the most efficient welding cycles.

Collaboration between Fraunhofer-Chalmers Centre, FCC, and Swedish vehicle manufacturers such as Scania CV, Volvo Cars, Volvo Trucks, and Saab Automobile resulted in a support software called Industrial Path Solutions or IPS. Since the introduction of the IPS software several companies have manage to implement the software.

In a competitive vehicle manufacturing market, companies are driven to always look for new ways of improving the production line. Consequently, faster production rates results in having the capability to produce more product within same time frame as before the improvement. With a new cab under construction an opportunity has presented itself to optimize the production line and improve the production rate at Oskarshamn cab assembly factory.

Today, Scania uses Delmia V5 for programming and simulating welding cycle. Unfortunately Delmia lack the functionalities that exist in Industrial Path Solutions, IPS, such as sequencing, load balancing, line balancing etc. With the help of the mathematical analysis in IPS, welding cycle time compared to an experienced engineer has been proven to reduce with around 20%. The thesis will be aimed at finding a more optimized path using simulations i.e. offline programming. This will be conducted with the help of a software tool called Industrial Path Solutions. By comparing the two different results a clearer insight on what the IPS actually optimizes. The most efficient welding cycle will depend on parameters such as cycle time, robot impacts and external impacts.
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1. Introduction

In [1] the car body is pointed out to be one of the most significant part of a vehicle; known as Body-in-White, BiW, it impacts characteristics such as top speed, fuel consumption, safety and handling. In today’s industry most of the path planning is performed manually instead of automated offline programming, thus consuming more time and eliminates the opportunity of finding the most optimized path.

A typical BiW described in [1] consist of approximately 300 sheet metal parts that is joined by around 4000 weld spots. BiWs are usually pre-assembled into under-body, body sides, roof and body closures separately before assembled into a complete BiW. Therefore all the weld spots have to be distributed amongst a number of robots; the number depends on the plant size, inside established robot cells or stations. The weld spots have to be distributed equally amongst every robot cells as well as robots to gain the most efficient welding cycles.

1.1 Background

This master’s thesis was initiated by the TDR Industrial Development department within Scania company; a smaller branch of TD – SPS & Industrial Development. TDR works with research and development within most of Scania CV’s industrial plants [2]. TDR works with the Scania Production Systems, SPS, as many other departments within production related processes. SPS is the philosophy and methodology on how Scania manufacture its products. As many other companies there is a pattern or a way to work when production is involved. This will be discussed further in the theory chapter.

In a competitive vehicle manufacturing market, companies are driven to always look for new ways of improving the production line. Consequently, faster production rates results in having the capability to produce more product within same time frame as before the improvement. With a new cab under construction an opportunity has presented itself to optimize the production line and improve the production rate at Oskarshamn cab assembly factory.

Collaboration between Fraunhofer-Chalmers Centre, FCC, and Swedish vehicle manufacturers such as Scania CV, Volvo Cars, Volvo Trucks, and Saab Automobile resulted in a support software called Industrial Path Solutions or IPS. Since the introduction of the IPS software several companies have manage to implement the software.

Today, Scania uses Delmia V5 for programming and simulating welding cycles [3]. Unfortunately Delmia lack the functionalities that exist in Industrial Path Solutions, IPS, such as sequencing, load balancing, line balancing etc. With the help of the mathematical analysis in IPS, welding cycle time compared to an experienced engineer has been proven to reduce with around 20%. Furthermore, the several months required for line balancing; distributing the work load amongst the available stations, have been proven to be reduced to about one day [1].

The major welding cycle paths are today created with the help of Delmia but when minor adjustments are implemented the assigned station is held up which stagnates the whole production line; adjustments are implemented with online programming. The possibility of
using the computation potentials exist in the Industrial Path Solutions and therefore Scania wants to explore the opportunity. Furthermore, the goal is to prevent the production line from stagnating. This leads to creating robot paths without contact to the robots i.e. offline programming which is explained more thoroughly in chapter 3.

By establishing the assigned station in the virtual world with the approximate position as in the real world station, there is no need for the production line to be held up. As the production line is manufacturing the product in the real world, the engineer can optimize the station by creating and testing different welding paths in virtual world. Moreover, robot codes; text and numbers signalling how the robots is supposed to move, can often be extracted from these software support tools.

1.2 Purpose

The thesis will be aimed at finding a more optimized path using simulations i.e. offline programming. This will be conducted with the help of a software tool called Industrial Path Solutions.

1.3 Goal

Create a robot cell that contains all the necessary parts in IPS software and finding a more efficient path than the existing one that is being used in production. By comparing the two different results a clearer insight on what the IPS actually optimizes. The most efficient welding cycle will depend on parameters such as cycle time, robot impacts and external impacts.

Figure 1.1. Industrial Path Solutions main window
1.4 Delimitations
The delimitation are based on the time frame.

- Creating simulations with new weld spot groups to each weld tool, hence only existing weld spot groups are simulated.
- The Load balancing and sequencing operations are based on finding the first available route, thereby not fully optimized.
- Research on the orientation of the weld spots since the ideal case is difficult to obtain.

1.5 Disposition of thesis
In this chapter the introduction is held; an overview of what the thesis is based on. Next chapter describes the method used in this thesis. All possible fields of interest are collected in chapter 3, Theory. The current station 50 and its working process is described in chapter 4; from bringing in the floor brought detaching the last fixture from the cab. In chapter 5, a description of each moment in creating a simulation in Industrial Path Solutions as well as all the parameters utilized in each moment. The results and finding from the IPS optimized simulations are presented in chapter 6. All errors that have or could have occurred under the projects path are presented in chapter 7. In Discussion chapter the results and findings of the optimized welding cycles are discussed. In the next chapter, Conclusions and Future work, conclusion are drawn and the delimitations are presented again with suggestions on how to perform those operations. Last chapter is the Reference, where all the data from chapter 3 comes from. Furthermore, an Appendix follows with all data that did not fit in the Result chapter.
2 Method

Before starting any programming or simulations, a thorough search within every relevant area have to be conducted. The most important area is the one explaining how to utilize the support software tools, IPS. The data concerning the IPS is going to be provided by the creators of the software while information about Delmia is going to be delivered by Scania. In addition to the data concerning the support software tools, information on spot welding is of interest since that is the procedure performed in the appointed station.

Since the two support software tools are created by two different companies a conversion of the geometries file format is essential. Consequently the conversion process will be executed using the current software, Delmia. To gain the information of the geometries whereabouts, constant contact will be held with the current users of the virtual weld stations at Scania. In addition to the geometries, weld spot data have to be obtained as well. To visualize weld spots in the virtual world two parameters are essential; coordinates and orientation. Hence a search within Scania’s database for this data is required.

With all geometries and data acquired, next step is to setup the station in the IPS software. To represent the station in the real world, the location of each geometry have to be extracted from the current support software and thereby relocating them in IPS as seen in Delmia. Therefore coordinates and orientations have to be retrieved from the same location as where the geometries are stored.

The simulations that will be created in the IPS are going to be created according to two cases; one with the same weld spot sequence as in the existing welding cycle and the other where the IPS configures the welding cycle. With the results from the two different cases comparisons can be performed both to the current welding cycle and also between the two simulation cases. Meetings will be held to update the participant within this project on the progress and results.

The final step in this thesis work is to write down the whole work process from retrieving the geometries to extract data from the simulations in a software called Enterprise Architect.
3 Theory

This chapter includes the literary study that was conducted within the fields of interest. The theory described in this chapter will be of interest when discussing the results and conclusions.

3.1 Scania CV AB

In 1902 the first Vabis truck was built and five years later [3], in 1908 the company had a target of 50 trucks per year but since the customer market had not adjusted to this kind of transportation the production decreased [4]. In 1909 the production slowed down to five trucks and seven cars which was a financial low point, the decision to phase out the vehicle manufacturing was made [4]. It was in the end of 1910 that Maskinfabriksasktiebolaget or Scania convinced Vabis to form a new company named AB Scania-Vabis which would take over all engine and car production responsibility [5]. Maskinfabriksasktiebolaget or Scania started out in Skåne; southern part of Sweden, hence the name Scania since it is a direct translation from Latin [3]. Same year as Scania-Vabis introduced the 14-litre V8 engine; that times strongest engine on the European market, in 1969 [3], [6], a merger between Saab; the former Swedish aeroplane and vehicle manufacturer, and Scania-Vabis which then became Saab-Scania. The Saab-Scania merger disengaged in 1995 and Scania became independent [3].

Scania [3] has become one of the world’s leading manufacturers of larger vehicle such as heavy duty trucks and buses; another area of importance is the industrial and marine engine production. Since the start of the company in the year 1910 Scania has not only opened up factories in different parts of Sweden but also in other countries such as Russia, Netherlands, Poland, France, Brazil and Argentina. The headquarters is still located in Södertälje where Scania was originally established.

Highlights such as production of Scania’s millionth vehicle occurred in year 2000; a truck [3]. The assembly of the truck was conducted in eleven different facilities located in five different countries with Zwolle, Netherlands, as its final station. In 2000, as well as the production of the millionth truck, Scania launched a 16-litre V8 engine and established a new factory for bus assembly in St. Petersburg, Russia. In the same decade Volkswagen AG ventured into Scania company by purchasing 37,4 million A shares which gave Volkswagen majority ownership in Scania [3], [7].

Scania has approximately 37,500 employees around the world, of those 37,500 roughly 9,000 works at the headquarters; 3,300 in production and development and 5,800 in finance as well as administrative areas. The sale numbers of 2011 indicates that Scania sold around 72,120 trucks, 7,988 buses and 6,960 engines (industrial and marine) [8], [9].

3.1.1 TD

TDR; were the R stands for Research, is an underlying branch of TD – SPS & Industrial Development [2]. TDs have the opportunity to work closely with the Scania Production System and improve it to support the line organisation, by Develop, Standardise and practical Train.
TDs mission are:

- Eliminate all deviations and accidents in production processes with training in practical leadership.
- Planning and supplying new workshops, plants and processes with developed, trained and sustained standards.
- Teach Scania’s managers in the application of SPS on challenging targets.
- Supplying Scania with up-to-date benchmark within chosen process.
- Networking with universities, colleges and other industries to gain long-term collaborations and skill needs.
- Develop, train and manage supportive tools e.g. digital factory, tightening technique etc..

3.2 Scania Production System

Scania production system [10], also known as SPS, is the philosophy and methodology that Scania works with when manufacturing its products. SPS was created and implemented in 1990s when the four main principles were established, “Normal situation – Standardised working method”, “Right from me”, “Consumption controlled production” and “continuous improvement’. The SPS scheme is in the shape of a house, with the four principles as building bricks and the foundation of the SPS consists of three major subjects: “Customer first”, “Respect for the individual” and “Elimination of waste”. See Figure 2.

![Figure 3.1. Scania Production System house.](image-url)
Above the foundation are the four main principles. “Normal situation – Standardised working method”, impels employees to maintain a standardised work process which makes it easier to notice the smallest deviations. Cost reductions could be achieved by noticing deviation in an early production stage due to lower waste. “Right from me”, deviations are not accepted; when deviations are noticed the shipment is stopped until correction has occurred. Correcting deviations before delivering helps creating a better customer relation; a satisfied customer generates more orders hence higher productivity. “Consumption controlled production”, never start manufacturing a product until a need is revealed. This principle prevents the company from overproduce a products thereby minimizing material waste. “Continuous improvement”, by improving the “Normal situation – Standardised working method” principle a lower number of deviations will occur.

Within the SPS house a priority list is displayed with four points, Safety/Environment, Quality, Delivery and Cost. The main objective is to reach all those points but if that is not possible the list in Figure 3.1 should be followed.

The purpose of SPS is to satisfy the customers demand as well as increasing the productivity thereby giving the company a major role in a competitive market. In production there is always an improvement opportunity which is why the SPS encourage employees to enlighten the engineers and thus improving the production. With the SPS every employee will participate in the improvement of the company as well as spreading the knowledge.

Absences due to sickness have decreased significantly and productivity has increased in a steady pace since the implementation of the SPS. An example of such case is the period between 2004 and 2007 when the productivity increased with up to 50 percent in Oskarshamn; cab assembly facility.

3.3 ABB

ABB was the product of a merger between Asea and BBC in 1987 which gave ABB total revenue of 100 billion kronor and 160,000 employees [11].

Asea was a merger between “Elektriska Aktiebolaget i Stockholm” and ”Wenströms & Granströms Elektriska Kraftbolag” in 1889 and stood for Allmänna Svenska Elektriska Aktiebolaget. In 1889 an engineer at Asea invented the delta system which included generator, transformer and engine. In the 1980s Asea was among the ten largest companies in the world. Before the merger with BBC, Asea had around 71,000 employees, revenue of 46 billion kronor and 70% of the sale where exports [11].

BBC was found in 1891 by Charles Brown and Walter Boveri. BBC had a major role in the European railroads with the electrification of a 20 kilometre long railroad for the Swiss government. Before the outbreak of world war one BBC delivered the largest steam turbine at that time. BBC Company had 97,000 employees and revenue of 56 billion kronor before the merger with Asea [11].
3.3.1 ABB robotics

ABB is today one of the leading distributor of industry robot, module based manufacturing system and service. ABB have installed over 190,000 robots all over the world, see [12]. Robotics unit have around 600 employees in Sweden; Västerås and Gothenburg. More than 90% of the production is exported to all kinds of companies all over the world [12].

3.4 IRB6400R_28_200

IRB6400R_28_200 [13] has a range of 2,8m and manages a weight of 200 kg, it consist of 6 axis and 6 joints. Each axis has a maximum and minimum range of movement this allows the axis to move within a certain area and also a maximum velocity.

The axis range of movement and velocity for IRB6400R are:

- Axis 1: +180° to -180° v = 100°/s
- Axis 2: +70° to -70° v = 100°/s
- Axis 3: +110° to -28° v = 100°/s
- Axis 4: +300° to -300° v = 210°/s
- Axis 5: +120° to -120° v = 150°/s
- Axis 6: +300° to -300° v = 210°/s

Each axis is attached to each other with a joint, see Figure 3.2. [13]

![Figure 3.2. Schematic overview of IRB6400R](image-url)
3.5 **Online and Offline programming**

Online programming, according to [14] is when the program is written onsite; involving the actual robot cell. With online programming constant robot awareness is a must; as the PLC, Programmable Logic Controller, or Teachbox is connected no other operations can be performed. With the robot always connected the advantage is that the robot will know the actual positions of the equipments with little or no deviation.

Advantages and disadvantages with online programming:

- Easy access.
- Reduced movement during programming.
- Logic and calculations are difficult to perform.
- Production rate of that station are down while programming.
- Poor documentation.

In [14], process of converting robot operations from simulations into robot language is called offline programming. The robot language depends on which robot manufacturer that is being used. Offline programming is a process where simulations are created in a virtual world containing the actual robot cell built in CAD, Computer Aided Design, models and therefore can be conducted without having to be onsite. Furthermore, another robot operation can be executed while programming, see [15]. Creating simulations beforehand gives the opportunity to make other calculation such as operation time, fastest path, costs, before implementing the program into the robot. As offline programming is conducted changes within real the robot cells or stations is a possibility which would not noticed in the simulation.

Advantages and disadvantages with offline programming:

- Logic and calculations are done more effectively.
- Easier to verify through simulations and visualisations.
- Well documented.
- Production is still up and running while offline programming.
- Demands investing in a support software tool.

3.6 **IPS**

Industrial Path Solution is a support software application created and introduced by Fraunhofer-Chalmers Research Centre for Industrial Mathematics (FCC). Extracted from [15], several years of collaboration between Wingquist Labratory at Chalmers and a group at Fraunhofer ITWM; responsible for the dynamics and durability, resulted in validated research that became the foundation of the IPS software. Other investors in the collaboration were Volvo Cars, Volvo Trucks, Saab Automotive and Scania CV. According to [15], there are two
existing modules in IPS which are IPS Path Planner and IPS Cable Simulation. With advanced algorithm and traditional graphical user interface, IPS can simulate flexibility of cables or hoses and its responses to impacts as well as the collision free paths when assembling an object.

Found in [16], a typical vehicle body consist of approximately a couple of thousand welds distributed amongst several hundred sheet metals. The welds are distributed amongst robots placed in different work stations. Production rate, when it comes to welding, is impacted by robot line balancing which is the balance between number of welds needed and how it is distributed amongst the robots. To minimize cycle time the welds have to be assigned to a specific robot in a specific station such that the stations load balancing, robot weld sequence and robot path planning is as effective as possible.

In the automotive industry weld load distribution are often done manually [16], thereby being time consuming with all the trial and error analysis operations that must be done. Robots have in some cases waiting positions or signals in its original path which impairs the cycle time and thus the production rate. IPS has therefore aimed at developing automatic simulations based on methods for weld load balancing and thus maximizing tool utilization and minimizing cycle time [16].

Evidence found in [16] showed that by implementing this software equipment utilization have improved with approximately 25% and a reduction in offline programming together with commissioning costs of approximately 75%. Tests showed that the IPS software improved the cycle time significantly compared to an experienced robot programmer.

3.6.1 IPS Path Planner

When searching for the most optimal path, without any collision, manually can be difficult. Thus, virtual methods can be of interest; using mathematical algorithms to retrieve a collision free path at minimum cycle time [18]. In the area of visualising assembly processes and path planning the existing virtual prototypes have not reached its full potential yet which results in manual programming of paths and motions. Geometrical accuracy is also a point to consider when implementing a virtual model into reality. IPS Path Planner takes the first step into making virtual models production adapted. With scene geometry the IPS Path Planner will find an efficient path and thus eliminating the need of manually program a collision free assembly path. IPS Path Planner manages Jupiter (jt) or VRML (.wrl) files which allows designer to import geometries from any CAD system.

Described in the PhD thesis [1], to minimize the calculation time for collision detection, the planning object are divided into boundary volumes instead of keeping only the 3D triangles which object commonly are made of in computer graphics. Highest on the boundary volume hierarchy is the planning object which is contained in one boundary volume and as further down on the hierarchy the more boundary volumes exist; the former boundary volume divides into two boundary volumes, until the lowest boundary volume contains one 3D triangle. As two objects collide, the boundary volume hierarchy tree can be search through instead of
pinpointing one 3D triangle in one huge list of 3D triangles. The boundary volumes create an easier way to narrow down the colliding 3D triangle.

The welding sequences are solved by the same algorithms used to solve the Traveling Salesman Problems, TSP. Explained in [1], the TSP can be described as mathematical algorithm to find the shortest way to visit all assigned spots and then return to the starting point. Since the amount of sequences is factorial to the number of weld spots i.e. 8 weld spots can generate around 40,000 different sequences, therefore a mathematical algorithm is used to find the optimal sequence. An algorithm is used for grouped TSPs, hence combining the two sub-problems; finding the shortest collision free path and the traveling salesman problem. With grouped multiple Traveling Salesman Problem, mTSP, the problem of both balancing and sequencing the distributed weld spots are solved within a minimized cycle time.

In stations with several robots sharing the workload, robot paths are bound to intersect therefore coordination is needed to avoid robot collisions [1]. Waiting time and velocity tunings are utilized in robot coordination. Grouped mTSP, except for automatic path planning, is also used for coordination which prevents the planning objects or robots to collide with each other. When coordinating, the station is divided into cube sized zones and if one robot has entered a zone the other robots are prohibited from entering the same zone. When it comes to manual coordination, which is often performed on-line, these cubical zones needs larger safety margins, however collisions may still occur. To determine zones where collisions might occur is for instance to create zones from the intersections of the swept volumes as the robots moves in their paths. Time within the collision zones can be determined by allowing the robots to move along its paths at full velocity.

3.6.2 IPS Cable Simulation

With the IPS Cable Simulation [19] flexible parts such as air pipes, fuel pipes, electrical wires, etc. can be simulated to determine its lifecycle. By using IPS Cable Simulation more scenarios can be eliminated before it becomes a reality. With the knowledge of the flexible parts material properties the forces and moments can be analysed and thus making it easier to evaluate the motion of the robot.

Material properties needed:
- Stretching stiffness.
- Stiffness for bending around x and y axis.
- Torsion stiffness.
- Length density.

3.6.3 Cost-effective Sheet Metal Assembly by Automatic Path Planning and Line Balancing, Integrated with Dimensional Variation Analysis

This was the PhD thesis that created the foundation of the Industrial Path Solutions software and where conducted at Volvo PV in Gothenburg with the collaboration of Fraunhofer Chalmers Research Centre; FCC. The aims of this project was to develop automatic simulations for weld load balancing to maximize equipment utilization and production rates,
thus proving that virtual programming improves cycle time compared to manual sequencing [1].

The research questions in [1] were based on two areas, “Automatic Path Planning and Optimization of Industrial Robots” and “Tolerance Analysis & Variation Simulation of Compliant Parts”. The available algorithms needed to solve the questions were utilized in a combined software-based research- and implementation-platform. The combination was between CAE-tool, Computer Aided Engineering tool, called Wingquist Laboratory Research Process and the DRM framework, Design Research Methodology.

In [1] the simulations conducted were based on 3 stations, 10 robots and 200 stud welds. The result showed a significant improvement in line cycle time compared to the previous used production programs and the time for the IPS to line balance were also reduced significantly. This PhD thesis proves that with mathematical algorithms such as the Traveling Salesman Problem, TSP, less time is needed to perform and calculate welding sequences. By utilizing several salesmen or “multiple salesmen” and thereby solving the multiple Traveling Salesman Problem i.e. distributing the welds evenly amongst the robots available in the station; load balancing. With the implementation of waiting times and velocity tunes the problem of preventing the robots from colliding with each other; robot coordination, is solved.

3.6.4 IPS at Saab Automobile

A bachelor thesis [15] was performed at Saab Automobile during the summer of 2010. The aim of the thesis was to optimizing the robot path in a welding station with the help of Industrial Path Solutions software and thereby proving that IPS were better than Saabs former support tool; IGRIP. The welding sequence was conducted on stud welds; see further in this chapter for more information on stud welds.

The problems the students stumbled upon were creating the Tool Centre Point, TCP, and the definition of orientation in the two support software. The TCP issue were solved by switching the X-axis with the Z-axis. The IGRIP defines the orientation in quaternion while the IPS defines the orientation in Euler angles. This was solved with the help of software that converted the quaternion to Euler angles. With the Euler angles and coordinates an easy implementation into the IPS were made.

The results in [15] gained from simulations compared to the previous robot path were an improvement of approximately 20%. The former robot path from IGRIP were replicated and established in IPS. The results indicated a welding cycle time of 27.88; while in reality that time increased to 47.78s, and the optimized welding cycle time, performed in IPS, resulted in a time of 22.28s.

The IPS 2.0 did not have a export function or a RCS-modul; Robot Controller Simulation. Without the export function and RCS a robot code could not be extracted from the software and therefore not implemented into the real robots. Hence, the thesis is restricted to the virtual world.
3.7 **Dassault Systems**

After the creation of Dassault systems in 1981, industrial companies have been able to improve the product development through digital mock-ups, 3D design and product lifecycle management (PLM). Since then the company has been concentrating on improving sustainable innovations and 3D experiences and become world leading in 3D digital mock-up, Product Lifecycle Management and 3D design software [20]. To go even further the company creates collaboration to generate more possibilities in the virtual world and thus improving the real world. The company has over 150,000 customers worldwide, both larger and smaller industrial companies [21].

3.7.1 **Delmia V5R19**

Delmia V5 provides manufacturers availability to virtually define, create, plane, monitor and control all production processes [22]. Opportunity to create a 3D visualisation of the real world gives engineers the chance to evaluate and eliminate “what-if scenarios” and thus prevent errors and design flaws.

The file based solution in Delmia [22]; General Assembly Planning, is used as a storage where enterprises can capture and re-use process knowledge, thus making it easier to share the information with product designers, planners and shop floor technicians. Through the use of an automated tool; Automatic Assignment Assistant, that automatically assign parts or sub-assembly to the proper step in the process plan hence planning time can be reduced.

Key functions with the General Assembly Planning:

- Capitalize and reuse assembly processes.
- Assignment of parts to the proper process step based on process precedence and the state of the assembly by using Automatic Assignment Assistant.
- Assembly process sequence verified in static 3D.
- Product design changes in the process plan with instant update.
- Generation of process documentation and product/process changes kept at up-to-date.

Process Engineer Enhancements attends to the needs of Consumer Goods and Automotive domains; areas were the numbers of product variations are high and thus requiring an agile process defining solution, by delivering Product Variant Matrix and Multiple Variant Line Balancing. Products with multiple variants are often divided into sub-process plans and then included at the correct step when product process variants. When a process changed, the planner had to evaluate and find the impacted product variants; an operation that could be time consuming. By utilizing the Variant Matrix, the product variants can be quickly identified in what processes and thereby reducing the evaluation time [22].

Key functions with Process Engineer Enhancements:

- Multiple product and process variants support.
• Process Variant Matrix; locate which sub-process assigned to what process variant.

• Process Variant Matrix; assign a sub-process to a process variant.

With Controlled Workcell Builder a combination of control logic and robotic simulation are available, this to provide a more powerful tool to integrate into the workcell design environment [22].

3.7.2 Catia V5 R19

Some areas that CATIA can be used in are:

• Mechanical Design
• Product Synthesis
• Analysis
• Shape Design and Styling
• Equipment and System Engineering
• Machining

In [23], Catia V5 Mechanical Design allows the user to accelerate the product development activities, from concept via detailed design and onto drawing production. The user has the capability to create parts in a highly productive and intuitive environment. With wireframe and basic surface features mechanical assembly constraints can be easily attached as well as automatically positioning parts. Communication between supplier and contractor is enhanced with the productive and intuitive design of sheet metal part solution. Linear and curved structures can be easily drawn using standard or user-defined sections. Engineering change management helps reduce the development time and cost by eliminating human errors and design inconsistencies.

In [24], Catia V5 Product Synthesis provides easy automation and validation of design and manufacturing data. The core function in product synthesis is the knowledgeware, it allows the user to capture and reuse corporate know-how throughout the product lifecycle. With the tools provided the user has the ability to make faster decisions amongst several combinations of parameters and constraints to gain the best alternative.

In [25], Catia V5 Analysis allows users to perform analysis directly on their master reference model in Catia. With the capability to perform rapid iterated design-analysis on both simple and complex assemblies. User-friendly environment for Catia users since the interface is a natural extension of that in Catia. With the Catia Analysis integrated in Catia the user will naturally use the analysis as a part of the design process thus improving the chance of making right the first time.
In [26], Catia V5 Shape Design and Styling provides tools to easily create, validate and modify all types of surfaces. The solution provides the user with functionalities to support surface modelling, editing and validation processes.

In [27], Catia V5 Equipment and Systems Engineering allow integration of electrical, fluid and mechanical systems within a 3D mock-up whilst designing. To manage the electrical behaviour of components as it is integrated into the 3D mock-up a product within Equipment and Systems Engineering called Electrical products provides tools for this purpose. Advanced platform for all Catia V5 diagramming allows the user to define the relation between 2D logical design and 3D allocation. Space reservations and allocations can be managed by optimizing electrical system routing layout and thus automatically route the pathways depending on the systems functional definition.

In [28], Catia V5 Machining provides solutions to plan, detail, simulate and optimize machining activities and thus obtaining better products. The user can increase production quality by machining right the first time due to the integration between tool path definition and computation, tool path verification and output creation. Time reduction, with the use of capture and reuse capability repetition can be avoided.

### 3.8 Resistance welding

Resistance welding [29], a process when heat is obtained from the resistance of the workpiece as a flow of low-voltage, high-density electrical current runs through. To ensure that the workpiece is welded together pressure is always needed, this to keep the circuit of the electrical current continuous which is done by the electrodes. Heat is an essential part of this process since no fluxes or filler metals are used. During the welding cycle the touching side of the two parts are heated to its plastic state and then pressure is applied to force the workpieces together.

Often used to supply the current is either a transformer or a transformer capacitor. The transformers are used to convert high line voltage power to high amperage current for low voltage welding. The pressure applied by the electrodes on the workpiece uses pneumatic, hydraulic or mechanical system and can be as little as between a few grams to thousands of kilos depending on the size of the welder and workpiece.

Common resistance welding machines consists of three important components:

- Mechanical system, enables the electrodes to apply a pressure and hold the workpiece at place.

- Transformer, capacitor and current regulator, to create the electrical circuit. If needed a second circuit to conduct the current to the workpiece.

- Control system, to regulate the welding cycle time.
Most common resistance welding processes are spot welding (RSW), seam (RSEW), high-frequency seam (RSEW-HF), projection (PW), flash (FW), upset (UW), and percussion (PEW) [29].

3.8.1 Spot welding

Most common resistance welding of all various sorts is spot welding [29]. The welding spots are formed accordingly to the electrodes as heat is conducted from one electrode through the workpiece to the other electrode. Together with the force applied by the electrodes a weld will appear at the centre of pressured place on the workpiece.

The welding time, or the time to weld one spot consists of four steps:

- The time period between the first application of the electrodes and the first application of the current; Squeeze time.
- The time period when the current flows through the workpiece; Weld time.
- The time period when the pressure from the electrodes is still applied but the current is off; Hold time.
- The time period when the electrodes breaks contact from the workpiece; Off time.

The time period of each stage depends on the spot welding machine and the thickness of the workpieces [29].

![Figure 3.3](image)

**Figure 3.3. Typical spot welding conditions [30].**

Figure 3.3 shows an approximate required weld time with a couple of specific parameters [30].

3.8.2 Stud welding

Stud welding is a form of resistance welding and almost like spot welding. Unlike spot welding were thin metal pieces are joined together; stud welding joins bolts or nuts to a metal surface. There are two basic types of stud welding; Capacitor Discharge and Drawn Arc. Capacitor Discharge or CD is used when smaller fastener are being welded, up to 5/16” in diameter. The process of Capacitor Discharge is a four step procedure, first step is the placement of the weld stud; one side goes into the weld head and the other placed against the workpiece. Second step is the discharge of electricity stored in the capacitors through the weld stud, thus making both the weld stud and the spot on the workpiece softer. third step is
the mechanical or pneumatic system forcing a fusion between the weld stud and workpiece, last step is when the weld head holds the weld stud at place for the metal to cool down [30], [31].

**Figure 3.4. Capacitor discharge; stud welding [30].**

1. Placement of the weld stud.
2. Electric current flowing from the capacitor through the weld stud.
3. Mechanical or pneumatic system forcing the weld stud and workpiece together.
4. Cool down time.
Drawn Arc [30], a process is almost similar to the CD process except that before the weld stud is forced onto the workpiece it is lifted so that an arc of molten metal is formed and then the weld stud is forced into the molten pool of metal. Drawn Arc process is used for larger weld studs such as 1” in diameter.

![ARC WELDING PROCESS](image)

**Figure 3.5. Arc weld; stud welding [30].**

1. Positioning of the weld stud.
2. Melting of the weld stud and workpiece by sending a current through the weld stud.
3. Lifting the weld stud to form a weld in arc shape.
4. Forcing the weld stud back into the form to be joined with the workpiece.

Since the process only takes a few milliseconds there is not enough heat to create markings on the opposite side and it can be used for almost all kinds of metals. With the fast process time stud welding can replace drilling and tapping to save time. [30]

### 3.9 Body-in-White

Body-in-White or Biw is a terminology used in the automotive industry to describe the vehicle body in its welded state; before anything is assembled into it, with a layer of primer, undercoat paint, see figure 3.6.
3.10 Enterprise Architect

The Enterprise Architect software [33], developed by Sparx Systems; established in 1996 by Geoffrey Sparks. The company is located in Australia and aims at simplifying planning, design and construction of intensive software systems with high performance and scalable visual modelling tools. Sparx Systems flagship product is the Enterprise Architect, introduced in 2000 and has now reached version 9.3 with approximately 300,000 users world-wide. Enterprise Architecture is managed by the use of UML; Unified Modelling Language, and other open standards with the potential of model-driven development. The vision of Sparx Systems is to provide a growing business and IT companies involved in software and systems development with a modelling and design tool that is sustainable during the full life cycle of a system development. Enterprise architecture is not only used in business and system development companies but also in colleges and universities for UML and business architecture training.

Enterprise Architecture can be used for:

- Business and IT systems
- Software and Systems Engineering
- Real-time and embedded development

Existence of the possibility to share easily and accurate comes with the usage of high quality documentation as well as sharing globally with integrated control capabilities. Enterprise Architect contains simulation capabilities which are used to verify and understand the business system. The simulation capability includes controls which can not only be used to control the flow of the simulation but also create calculations at a certain time into the simulation. There is also a trace function which can be used to trace changes in the business system or even the original requirement list of the product/service. In addition, the possibility to debug, compile and visualise execution codes exist. This enables any company to integrate
a test process into the Enterprise Architect thus being able to combine UML and modelling into each step, from building, testing, executing to deploying. With the debugging function a stack trace can be captured from the execution code which can then be transformed into visual sequence diagrams.
4 Station 50

In station 50 there were two robots of the IRB6400R kind which was produced by ABB and in station 55 there were also two robots of the same kind; IRB6400R. A transportation line for the robots also called tracker connects these two stations together and allows the four robots to travel into each other’s areas therefore the station was also called station 50-55. The left robot was named R8B11 and the right was named R8B12. From here and forth only station 50 will be described

![Figure 4.1 Station 50 combined with station 55, without the cab.](image)

The P19 process in the former station 50 began with a fixture transporting the floor to the designated location; at the centre of four fixture pillars. When the floor was at place, two gudels; a pick and place robot attached to a girder, transported the front wall and rear wall which were attached to fixtures. The fixture pillars assignment was then to hold the fixtures at place hence the two walls would be fixed to the floor. At this point the two girders left the area and the two of the three last pieces; roof frame and strengthening beam, were brought to the assembly by the two IRB6400R robots in station 50. With five out of six pieces at place the welding cycle were started; the last piece was the roof which was introduced in a later phase. The robots first tool to start station 50’s welding cycle was the Gc008 and Gc007; the welding cycles will be described in chapter 5. The first and second tools welding cycle were performed before adding the roof into the assembly which was brought in by one of the gudels. With the fixture holding the roof at place, the robots executed the third and fourth tools processes. After the fourth tools welding cycle, the girders started to move into the area to remove the three fixtures that held the assembly together; which were now the weld spots assignment. The tools processes are described in chapter 5.
The path planning of station 50 was originally conducted with off-line programming but as time progressed minor improvements were therefore made with on-line programming. Those improvements were conducted in online programming, thus making the current robot path only available in reality. The welding cycle time per tool are presented below.

The real world welding cycle time in station 50 (the time is approximate):

- Total time of both robots with Gc001 tools: 54 seconds
  - R8B11 with Gc001: 47 seconds
  - R8B12 with Gc001: 40 seconds
- Total time of both robots with Gc007/Gc008 tool: 50 seconds
  - R8B11 with Gc007: 50 seconds
  - R8B12 with Gc008: 28 seconds
- Total time of both robots with Gx301 tools: 67 seconds
  - R8B11 with Gc007: 56 seconds
  - R8B12 with Gc008: 65 seconds
- Total time of both robots with Gx305 tools: 111 seconds
  - R8B11 with Gc007: 107 seconds
  - R8B12 with Gc008: 111 seconds
5 Industrial Path Solution

This chapter will describe how all data was collected; data that was necessary for the usage of
the IPS software and each step in creating the simulations, from converting files to extracting
data from former software, Delmia. Station 50 will from here on be referred as the station.

5.1 IPS introduction

An introduction was held at the Fraunhofer Chalmers research Centre, FCC. The goal of the
introduction was to explain the basics of the IPS software and give a test run on a prepared
weld cycle. The basics explained during the introduction was tasks such as importing parts,
changing views, creating and naming subgroups etc. The IPS software could import two
different file formats VRML; also known as .wrl, and Jupiter (.jt), however the IPS saves files
in .ips formats. Other basic such as the structure of parts, the interface, static geometry, active
objects and how to create a simulation was also explained.

- Main groups: There were two categories within the IPS Scene; static geometry and
  active objects. What separates the two groups are kinematic characteristic; static
  geometry group contains parts with no movements i.e. no kinematic data while active
  objects group contains the parts with kinematic data

- Subgroups: The option to create groups within the two main groups was available. The
  advantage with subgroups in static geometry was the possibility to move several parts
  without increasing/decreasing the distance between the parts in the subgroup, similar
  possibility existed in active objects.

- Planning Process: A process window that contains the operations to create
  simulations. Planning Process contains two main steps; Overview and Sequence. Parts
  needed before being able to create a Planning Process were robots, tools with TCP,
  weld spots and work object.

  o Overview: Contained the “Plan Tasks” operation.

    ▪ Plan Task: An operation for verification of the TCPs possibility to
      reach the chosen weld spots. The weld spots had to be located and
      oriented in a way that the tools TCP could match for the Plan Task to
      approve the found solution. In addition to the verification, the Plan
      Task calculates all possible alternatives the robot joints could have with
      the TCP at the weld spots location; alternatives are referred as solutions
      in IPS.

      Parameters in Overview:

    ▪ Soft angle limit: Reduces the robots joints max/min limit in the virtual
      world with the number entered; as a safety margin. Used in case weld
      spots relocates and thus needs to be corrected onsite.
- Clearance: Minimal allowed distance between active objects and static geometry.
- Weld time: The time which the electrodes are in contact with the work object i.e. in its closed state.
- Electrode diameter: The diameter of the electrode.
- Extra height of the cutting cylinder: The function of this parameter is to create an empty cylindrical area around the weld spot and thus verify where the electrodes impacts with the nearby sheet metal. The parameter creates two cylinders, one on each side of the weld spot. The diameter of the cylinder is the electrodes diameter plus clearance.

![Figure 5.1. Available parameters when task planning.](image)

- Sequence: Contained operations such as plan inter paths, plan sequence, load balance and sequence, and coordinate. The Overview step has to be operated and approved before being able to work on the Sequence step.
  - Plan inter paths: Calculates the robots path between weld spots
  - Plan sequence: Calculates the order and path of which the weld spots should be taken to obtain an optimal welding cycle time.
  - Load balance and sequence: Performed when the simulation contains more than one robot. The IPS distributes the chosen weld spots amongst the available robots and then calculates the weld spots order and path for each robot. See figure 5.2.
  - Coordinate: Calculates the robot movements to avoid impact between robots.
Parameters in Sequence:

- Clearance between robots: Minimal distance the robots must have to each other.
- Max time per path planning: The time which the IPS had for disposal. When the time runs out the calculations will stop even if no solution had been found.
- Minimum gap to optimum solution: Parameter that decides how close the solution will be to the most optimal solution. Can be changed from 0 to 1; 0 to obtain the most optimal sequence and 1 to obtain the first found sequence.
- Maximum number of iterations: One loop is from creating sequence to load balancing and then path planning. Max number of iteration the software got to find the solution which depends on the “Minimum gap to optimum solution”.

**Figure 5.2. Available parameters when Load balance and sequencing.**

Another function in the planning process was the path analysis which could be used to pinpoint a desired time in the welding cycle for analysis.

### 5.2 IPS preparation

Since the cab model were taken from CATIA the parts were in .cgr file format thus the parts had to be converted into either .wrl or .jt; in this case the parts were converted to .wrl. The parts were converted by opening in CATIA and then saving the parts as .wrl thus being able to open in IPS software.

Without the possibility to retrieve a robot from a robot library, kinematic data on that robot had to be retrieved. Every moveable object in the station must have some kind of kinematic data which could be retrieved from the manufacturer or an earlier project including the same station. The robots kinematical data were retrieved from ABBs product data sheet for IRB6400R; the robots used in the station. Useful data found in the product data sheet was max/min range of movement for each axis, velocity of each axis and schematic overview of the robot. Since not all data could be found in the product data sheet the usage of ABB
simulation software; the software used by ABB to simulate robots also called robotstudio, was necessary. Joint dependence; the change of a joints rotation value affects the nearby joint rotation limits, were tested and found. By first rotating one joint to its max/min limit and register those values then keeping the joint in its max limit and rotating the nearby joint to its max limit. If the min value had changed on the first joint then the joints are dependent on each other. This method was conducted in robotstudio, on all six joints for verification since IPS 2.0 could not support joint dependency. Homeposition for each robot was retrieved from the robot backup program; codes and coordinates for every movement of the robot. All this data and models of the robot were sent to FCC for construction and implementation of kinematics.

Furthermore, the kinematic data for the trackers was also needed since it was a moveable part in the station. Kinematic data of the trackers such as joint max/min value and velocity was delivered by a production engineer at Oskarshamn factory. The kinematic data for the trackers could be created with a function called puzzle objects which would allow an object to either move in a linear pattern, revolute or flip. In this case the trackers were allowed to move in a linear path with joint max and min values as its limits. Last moveable part that was needed to create a complete simulation of the welding cycle was the welding tools. The information needed from the different welding tools were the joint values at open, semi-open and closed state as well as the TCPs location in reference to the base plate position. This information together with the models was also sent to FCC for integration of the kinematics.

Importation of parts; Cab, station, robots, transportation tracks, were made with the station as reference i.e. the stations origo were matched with the starting origo. With only the station imported a general overview could be seen on where the rest of the parts might be located. By searching through another project in Delmia involving the station, positions for every part in the station were found. Since the parts were all in .cgr files which is the format used in Catia, the parts had to be converted into VRML format to be able to use in the IPS software.

The parts and coordinates were:

- P19 cab                   (-9300,9000,152)
- Transport track 1;Home    (-3099.47,6310,900)
- Transport track 2;Home    (-7035.81,11700,900)
- Robot 1 (R8B11;Home)      (-3099.47,6310,900)
- Robot 2 (R8B12;Home)      (-7035.81,11700,900)
- Front fixture             (-9300,9000,152)
- Top fixture               (-9300,900,152)
- Rear fixture              (-9300,9000,152)
- Roof table                (-6783,3890,-601.7)
An importation of the robots and weld guns were done after receiving them from FCC. The robots in the station were placed on platforms which transports the robots; also called transportation tracks, this made it possible for the robots to reach every weld spot. The tracker movements were created with the help of a function called “Puzzle object” which allows an object to travel in an assigned direction with a max and min limit. The station were categorised in a geometry group called “Station 50”, the cab in one called “Cab P19”. The four robots were divided into separate groups, each group containing a “Puzzle object” function that allows the robots to be transported to a desired coordinate.

The points represented in the IPS were called general features and contained only coordinates and orientations. There were two options of implementing the general features, first option was to create the features inside the IPS software and the second option was to import a .features file containing the information. The first option would be more time consuming since every point had to be created manually while the second option the points would be created automatically with the information inside a .features file. The structure information inside the .features file had to be in the order of: Name, x-coordinate, y-coordinate, z-coordinate, x-orientation, y-orientation and z-orientation. The general features points could then be converted into either spot welds, homepositions or stud welds.

The information used in Delmia to weld a spot was written in .xml files and included more information than in a .features file i.e. sheet metal thickness, sheet metal part, normal of the sheet metal as well as coordinates and orientation. To extract the coordinate and orientation data from the .xml file and pasting the data in a .features file a script was needed. Visual basic script was used to try and extract the data from the .xml file. A script was almost finished but fortunately there was a existing macro script that extracted the data from a .CATPart containing half of the P19 cab, see figure 5.3.

![Figure 5.3. Weld spots](image)

The weld spots in the .CATPart file were represented by dots which only gave coordinate information and not the orientation. A reflection of all weld spots were made since the .CATPart only contained half of the P19 cab, with the cabs y-axis as the mirror. The extracted
data were then pasted in an .xls file with names and coordinates listed. The extracted .xls file contained more spots than what was handled in the station; approximately 67 weld spots of the 449 weld spots found on half the P19 cab. A search within the latest robot backup program had to be conducted. The robot backup program contained information on which weld spots belonged to which weld tool and sequences of each weld tool. To eliminate the redundant data a slow process had to be implemented; by matching the names of the weld spots in the latest robot backup programmes with the ones in the .xls file thus retrieving the right weld spots. The relevant data was then copied from the .xls file and pasted in a .features file.

Since the .xls file retrieved from the .CATPart file contained names and coordinates of the P19’s weld spots while the robot backup program file contained weld tools and weld spots for the station, a simple search, copy and paste were conducted. With the weld spots divided into different .features files depending on which tool, separate sub weld cycles were established. The retrieved data only contained the coordinate information and not the orientation which had to be adjusted manually; with the z-axis pointing approximately in the same direction as the normal vector of the plane.

There were two criteria that had to be fulfilled by the weld spots to be able to create simulations. First criteria was that the added features could not be further apart from the work object then the thickness of the sheet metals thus making it possible to convert the features into weld spots. Second criteria were the orientation; the z-axis had to have approximately the same orientation as the normal vector of the plane and in the direction for the tools TCP to be able to reach and match.

5.3 Verification on welding tools and spots
To be certain which tools could weld which spots, verification tests were performed. With all weld spots inserted into the cab, plan task function was executed for each welding tool. There was approximately 133 spots to be welded in station 50 with four welding tool at the robots disposal. The verification test was performed with the plan task function which would either present a green or red box with the number of possible solution for a given weld spot. The roof was brought in at the middle of the welding cycle, therefore the plan task had to be performed twice; once without the roof and once with the roof.

- Parameters set in the Plan Task operation:
  - Clearance: 1 millimetre
  - Weld time: 2 seconds
  - Electrode diameter: 16 mm
  - Extra height of the cutting cylinder: 5 mm
5.4 IPS simulations

The original welding cycle of station 50 was divided into 4 sub weld cycles; each sub weld cycle containing one pair of tools, since the station contained more assembly operations which could not be simulated in the IPS. Therefore, the sub cycles contained only simulations of welding operations and no other processes. The weld spots were imported into the structure by a .features file containing the weld spots coordinates and pre-orientation; the orientation were set to (0,0,0) which were changed manually inside the software.

5.4.1 Tools

There were four kinds of tools used in the station, Gc001, Gc007/Gc008, Gx301 and Gx305. Each tool would thus have its own homeposition as would the robot without any tool. The homepositions were extracted from the robot backup programs.

Each tool will be described below, how many weld spots each tool were assigned with and which walls the weld spots connected.

5.4.1.1 Gc001 and Gc001

With a half circle form and short fingers gave this tool the advantage of getting close to the weld spots hence travel within tight areas.

![Figure 5.4. Gc001 welding tool.](image)

The weld cycle for Gc001 contained 16 weld spots; 8 weld spots on each robot. 6 weld spots were located on the front; welding together the front wall with the strengthening beam. While the other 10 weld spots were located on the rear; welding together the rear wall to the floor.

As the verification test indicated that the Gc001/Gc001 combination could be replaced by the Gc007/Gc008 combination, therefore two separate simulations were created.

Figure 5.5 and 5.6 shows the area where the weld spots are located for the Gc001/Gc001 weld cycle.
Homeposition for the tool were extracted from the old robot backup program. The numbers within each square bracket describes what degree the joints had when standing at its homeposition.

Joint number follows in the same order as the order in the square bracket, i.e.
HomeGun301:=[Joint1,Joint2,Joint3,Joint4,Joint5,Joint6],[Joint7,Joint8,Joint9,Joint10,Joint11,Joint12];
Homeposition right tool:

!Declaration of Homeposition

\[
\text{CONST jointtarget HomeGun301:=}\begin{bmatrix}
-117.14, -5.87, 8.08, 0, 81.93, -115.8 \\
3000, 9 \times 10^9, 9 \times 10^9, 9 \times 10^9, 9 \times 10^9, 9 \times 10^9
\end{bmatrix}
\]

*Figure 5.7. Homeposition of R8B12 with Gc001.*

Homeposition left tool:

!Declaration of Homeposition

\[
\text{CONST jointtarget HomeGun301:=}\begin{bmatrix}
107.98, -22.91, -2.47, 0, 92.47, 108.8 \\
4000, 9 \times 10^9, 9 \times 10^9, 9 \times 10^9, 9 \times 10^9, 9 \times 10^9
\end{bmatrix}
\]

*Figure 5.8. Homeposition of R8B11 with Gc001.*
5.4.1.2 Gc007 and Gc008

The tools had a half circle form with a deep pocket which made it possible for the tools to both reach and manoeuvre in small areas.

![Figure 5.9. Gc007 welding tool](image)

![Figure 5.10. Gc008 welding tool](image)

The Gc007 had 11 weld spots on the left side; 5 weld spots connected the floor to the front wall. The other 6 weld spots on the top of the front; 3 weld spots connected the roof frame to the front wall and the other 3 weld spots connected the front wall, strengthening beam and roof frame together. Gc008 had the 6 weld spots on the top of the front; 3 weld spots that connected the roof frame to the front wall and the other 3 weld spots connected the front wall, strengthening beam and roof frame together. Hence, the weld cycle of the Gc007/Gc008 had a total of 17 weld spots, see Figure 5.11. The Gc001 and Gc007/Gc008 had a rather similar form. Consequently two separate simulations were created for this cycle; one with the Gc007/Gc008 and the other with Gc007/Gc001 combination. Wait positions were added to the cycle as well since the original sequence contained two wait positions on each tool. The
first wait position were added between the first and second upper weld spot; the weld spots that joins the roof frame to the front wall. Second wait position was added between the third and forth weld spots; right before the strengthening beam is added to the assembly.

In this case a load balance and sequence operation would not reflect the original sub weld cycle of the Gc007/Gc008 due to the interaction with the front fixture. Therefore, the weld spots were manually sequenced and thereafter a plan inter paths operation were performed; the order of the weld spots can thereby match the original sub cycle of the Gc007/Gc008.

![Figure 5.11. Weld spots for Gc007/Gc008 tools.](image)

Homeposition right tool:

```plaintext
!Declaration of Homeposition

CONST jointtarget HomeGun302:=([-145.71,-21.68,12,0,78,125.58],[4000,9E+09,9E+09,9E+09,9E+09,9E+09]);
```

![Figure 5.12. Homeposition of R8B12 with Gc001.](image)
Even though the Gc008 tool was substituted with the Gc001, the homeposition was kept as if the robot were holding the Gc008 tool.

Homeposition left tool:

!Declaration of Homeposition

\[ \text{CONST jointtarget HomeGun302:=} \{[110.45,-13.89,-1.9,0,91.95,-69.2], [4000,9E+09,9E+09,9E+09,9E+09,9E+09] \}; \]

5.4.1.3 Gx301 and Gx301

Third tool was the Gx301 with the long fingers; the size of the fingers made it possible for the tool to reach weld spots that were located close to the centre of the roof. With the distance from the side to the spots around the centre, the Gx301 was necessary to reach the spots. This tool also welds the roof together with the rear wall.

Figure 5.14. Gx301 welding tool
This tool was used in the third sub weld cycle and contained 24 weld spots; 11 weld spots on the left side, R8B11, and 13 weld spots on the right side, R8B12. The first 18 weld spots connected the roof frame to the roof and the other 6 weld spots connected the roof to the rear wall.

Figure 5.15. Weld spots of the Gx301 tools on the roof, viewed from above.

Figure 5.16. Weld spots of Gx301 tools on the rear wall, viewed from behind.

Homeposition right tool:

!Declaration of Homeposition
CONST jointtarget HomeGun303:=
[[55.7,-12.46,-16.01,0,106.02,-34.3],[119.998,9E+09,9E+09,9E+09,9E+09,9E+09]];
The homeposition was not correct when implementing the joint value, thus a research within the available video material was conducted. Results provided that joint6 should be turned 180 degrees, see figure 5.17.

Homeposition left tool:

`!Declaration of Homeposition
CONST jointtarget HomeGun303:=[[91.77,-18.69,21.86,-0.22,50.52,181.95],[-0.00207005,9E+09,9E+09,9E+09,9E+09,9E+09]];`
5.4.1.4 Gx305 and Gx305

The Gx305 had short fingers which made it possible for the robot to manoeuvre in tight areas. After finishing the welding cycle for the Gc007/Gc008 tool the robots switches over to the next tool; the Gx305 welds together the rear wall to the roof frame and the front wall to the strengthening beam.

![Gx305 welding tool](image)

**Figure 5.19. Gx305 welding tool**

Gx305 was the tool with most weld spots in this station; a total of 76 weld spots. The first six weld spots connected the lower part of the rear wall to the floor, the next 38 weld spots connected the roof frame to the rear wall. The last 32 weld spots connected the front wall to the strengthening beam.

![Weld spots of Gx305 tools, viewed from above.](image)

**Figure 5.20. Weld spots of Gx305 tools, viewed from above.**
Homeposition right tool:
!Declaration of Homeposition
CONST jointtarget HomeGun304:=[[93.79,-20.39,0.46,-25.89,62.67,83.52],[1394.33,9E+09,9E+09,9E+09,9E+09,9E+09]];

Homeposition left tool:
!Declaration of Homeposition
CONST jointtarget HomeGun304:=[[-90,-35.7,0,0,90,0],[600,9E+09,9E+09,9E+09,9E+09,9E+09]];

Figure 5.21. Weld spots of Gx305 tools, viewed from left and right side of the cab.

Figure 5.22. Homeposition of R8B12 with Gx301
5.4.2 Simulations

The parameters set for this simulation:

- In the Plan Task operation:
  - Soft angle limit: 5°
  - Clearance: 1 millimetre
  - Weld time: 1 seconds
  - Electrode diameter: 16 mm
  - Extra height of the cutting cylinder: 5 mm

- In the Plan Sequence operation:
  - Clearance between robots: 30 mm
  - Max time per path planning: depended on which sequence.
  - Max calculation time: depend on the chosen sequence
  - Minimum gap to optimum solution: 1
  - Maximum number of iterations: 1000

Every weld spot had to be accessible by the given tool; this was verified by creating a plan task which existed inside the “Planning Process”. The plan task function also presented, if possible, a couple of alternatives on how the robot could be angled for the weld tool to reach...
the specified spot which were called “solutions”. These solutions were then available when creating sequences of the weld spots. First objective after the plan task was to load balance and sequence which also existed inside “Planning Process”, under Sequence tab. The load balance and sequence process was the last step in creating a simulation. Since the station consisted of more than one active robot, coordination was a must. The coordination hinders the active robots from entering an occupied zone by implementing either wait signals or reducing the velocity. After each simulation a path analysis was extracted, the analysis describes the robots distance to the closest object while performing its welding cycle.

5.5 Enterprise Architect
With Enterprise Architect [32], software created Sparks Systems, the work method of creating a simulation in Industrial Path Solutions was formed. The scheme was built up by Activity, Object, Partition and Decision boxes. The Activity boxes are filled with step by step instructions on how the user should proceed with creation of IPS simulations. Object boxes were located between each Activity box to describe the station as the Activities were performed. Partition boxes were resources and specifications needed before and during the performance of creating simulations. As the scheme is followed, a couple of Decision boxes are placed out to make sure the users have the appropriate parts to continue. Last decision in the scheme is the one asking if the welding cycle time is acceptable, if not then the user should go back to the step where simulations are created and lower the “Minimum gap to optimum solution” for a better cycle time. If the answer is yes then the user should go to the step where the robot code is implemented.
6 Results

In this chapter, the results obtained from optimized welding cycles using the Industrial Path Solutions, IPS, are presented.

6.1 Verification on welding tools and spots

The result from these verification tests gave a clearer insight on the possibility of either replacing or switching welding tools. The two task plans were then attached into one list. The entire list can be observed in Appendix A; the * indicates that the weld spots belongs to the weld tool of that column.

![Figure 6.1. Task planner; weld spots solutions for Gc007/Gc008.](image)

6.2 Gc001 and Gc001

The parameter set individually for the original simulation:

- Max time per path planning: 90000 seconds.

The results from the optimized path with the original sequence:

- Time utilized of the “Max time per path planning”: 55800 seconds
- Welding cycle time with both robots and Gc001 tools: 35.3482 seconds
  - R8B11 with Gc001: 28.6786 seconds
  - R8B12 with Gc001: 32.221 seconds
Figure 6.2. R8B11 and R8B12 distance from closest object during their paths; original sequence in IPS.

Figure 6.2 shows either the robots or the tools distances to the closest objects; green represents the R8B11 robot and the blue represents the R8B12 robot. The closest distance to an object was between the Gc001 tool on the R8B11 and the front wall; approximately 2.3 millimetres. The optimized path configured by the IPS with the same sequence as the original gave an improvement of approximately 34%.

The parameter set individually for the IPS configured simulation:

- Max time per path planning: 90000 seconds.
- Max calculation time: 259100 seconds.

The results from the optimized path where the IPS load balanced, sequenced and path planned:

- Time utilized of the “Max calculation time”: 29502 seconds
- Total time with both robots and Gc001 tools: 34.0829 seconds
  - R8B11 with Gc001: 27.6918 seconds
  - R8B12 with Gc001: 32.3333 seconds
Figure 6.3 shows the shortest distance measure between R8B11 robot with the Gc001 and the closest object in green colour and R8B12 robot in blue colour. The shortest distance between either the robot and the closest object or the tool and the closest object depended on which of the two alternatives was the smallest. The shortest distance during the entire path were between the Gc001 tool on the R8B11 robot and the front wall; the distance was 4.5 millimetres. The improvement of the Gc001 welding cycle was approximately 37%.

### 6.3 Gc007 and Gc008

With the result from the verification test a second simulation was created for the Gc001/Gc001 welding cycle but instead of the Gc001 tools a Gc007/Gc008 combination was utilized.

The parameter set individually for the original simulation:

- Max time per path planning: 1814400 seconds

The results from the optimized path with the original sequence:

- Time utilized of the “Max time per path planning”: 265850 seconds
- Total time with both robots and Gc007/Gc008 combination: 39.1905 seconds
  - R8B11 with Gc007: 32.959 seconds
  - R8B12 with Gc008: 31.0753 seconds
Closest distance to nearest object can be seen in figure 6.4. Green curve represents R8B11 and the blue represents R8B12 robot. The closest distance arises between the Gc007 tool on the R8B11 robot and the rear wall; distance between the two geometries were 1.23 millimetres. The IPS improved the original sequence with approximately 27% with optimized path planning i.e. with the paths planned by the IPS, the welding cycle time reduces with 27%.

The parameter set individually for the IPS configured simulation:

- Max time per path planning: 108000 seconds
- Max calculation time: 1814400 seconds

The results from the optimized path where the IPS load balanced, sequenced and path planned:

- Time utilized of the “Max calculation time”: 70246 seconds
- Total time with both robots and Gc007/Gc008 combination: 39.9841 seconds
  - R8B11 with Gc007: 38.0296 seconds
  - R8B12 with Gc008: 38.5799 seconds
Figure 6.5 shows robot R8B11 in green and robot R8B12 in blue. The graph shows either the two robots or the tools distance to the closest object while performing welding cycle operation; which of the two alternatives depended on the shortest distance. The shortest distance was between the tool when moving between two close weld spots; approximately 1.78 millimetre. The improvement of the Gc001 welding cycle but with the Gc007/Gc008 tools was approximately 26% i.e. the time of the welding cycle reduces with 26%.

6.4 Gc007 and Gc008

Only 12 of the 17 weld spots were involved in this optimization. Together with the 12 weld spots, four wait positions were added to the cycle; two wait positions to each tool.

The parameter set individually for the original simulation:

- Max time per path planning: 1814400 seconds

The results from the optimized path with the original sequence:

- Time utilized of the “Max time per path planning”: 23211 seconds
- Total time with both robots and Gc007/Gc008 combination: 19.834 seconds
  - R8B11 with Gc007: 19.834 seconds
  - R8B12 with Gc008: 18.7409 seconds
Figure 6.6. R8B11 and R8B12 distance from closest object during their paths; original sequence in IPS.

Figure 6.6. displays closest distance between active objects and static objects; green represents R8B11 and blue represents R8B12. In this case the shortest distance was between R8B12 and the roof frame; approximately 2 millimetres. Comparing IPS path planning to the original sequence, the IPS reduces the cycle time for the same sequence with approximately 46%.

The parameter set individually for the IPS configured simulation:

- Max time per path planning: 90000 seconds
- Max calculation time: 1814400 seconds

The results from the optimized path where the IPS load balanced, sequenced and path planned:

- Time utilized of the “Max calculation time”: 17638 seconds
- Total time with both robots and Gc007/Gc008 combination: 17.2308 seconds
  - R8B11 with Gc007: 17.2308 seconds
  - R8B12 with Gc008: 17.0946 seconds
Figure 6.7. R8B11 and R8B12 distance from closest object during their paths; IPS load balanced and sequenced.

Graph in figure 6.7. shows robot R8B11s distance to the closest object in green and R8B12 in blue. The shortest distance existing in this sub cycle was between the Gc007 and the roof frame; approximately 2 millimetres. The IPS configured load balancing and sequencing optimized and reduced the cycle time with approximately 53%.

6.5 Gc007 and Gc001

The result from the verification tests also showed that the Gc001 could weld the same spots as the Gc008 tool hence another simulation was created for this sequence.

The parameter set individually for the original simulation:

- Max time per path planning: 1814400 seconds

The results from the optimized path with the original sequence:

- Time utilized of the “Max time per path planning”: 46891 seconds
- Total time with both robots and Gc007/Gc001 combination: 20.8302 seconds
  - R8B11 with Gc007: 20.8302 seconds
  - R8B12 with Gc001: 20.2362 seconds
Figure 6.8. R8B11 and R8B12 distance from closest object during their paths; original sequence in IPS.

Figure 6.8 shows either the robots or the tools shortest distance to the closest static object, R8B11 represented by the green curve and R8B12 by the blue curve. The shortest distance was found between the Gc001 tool on the R8B12 robot and the roof frame; the shortest distance was approximately 2.3 millimetres. The IPS optimized the first sub cycle with approximately 44% utilizing the original sequence.

The parameter set individually for the IPS configured simulation:

- Max time per path planning: 90000 seconds
- Max calculation time: 1814400 seconds

The results from the optimized path where the IPS load balanced, sequenced and path planned:

- Time utilized of the “Max calculation time”: 15110 seconds
- Total time with both robots and Gc007/Gc001 combination: 17.8086 seconds
  - R8B11 with Gc007: 16.8314 seconds
  - R8B12 with Gc001: 17.8086 seconds
Figure 6.9 shows the shortest distance between the robots or the tools and the static objects, R8B11 seen in green coloured curve and R8B12 in blue. The shortest distance was found between Gc001 tool and the roof frame of approximately 2.8 millimetres. Improvement of the first sub cycle utilizing the IPS configured sequence was approximately 52%.

6.6 **Gx301 and Gx301**

The parameter set individually for the original simulation:

- Max time per path planning: 1814400 seconds

The results from the optimized path with the original sequence:

- Time utilized of the “Max time per path planning”: 36676 seconds
- Total time with both robots and Gx301 tools: 33.4124 seconds
  - R8B11 with Gx301: 27.9171 seconds
  - R8B12 with Gx301: 33.4124 seconds
Figure 6.10. R8B11 and R8B12 distance from closest object during their paths; original sequence in IPS.

The curves in figure 6.10, green represents R8B11 and blue represents R8B12, indicates the robots and tools distance to the closest object. The closest distance was between the Gx301 tool on the R8B12 robot and the roof; approximately 2.8 millimetres. Recreating the same sequence as the one used in original station for Gx301, the IPS optimized and improved the Gx301 welding cycle with approximately 50%.

The parameter set individually for the IPS configured simulation:

- Max time per path planning: 108000 seconds
- Max calculation time: 1814400 seconds

The results from the optimized path where the IPS load balanced, sequenced and path planned:

- Time utilized of the “Max calculation time”: 40624 seconds
- Total time with both robots and Gx301/Gx301 combination: 34.7464 seconds
  - R8B11 with Gx301: 34.5709 seconds
  - R8B12 with Gx301: 34.7464 seconds
Figure 6.11. R8B11 and R8B12 distance from closest object during their paths; IPS load balanced and sequenced.

Figure 6.11 shows the shortest distance between active and static objects, the green represents the R8B11 robot and blue represents the R8B12 robot. The shortest distance was between the Gx301 tool and the roof of the cab; a distance of 2 millimetres. The improvement of the IPS configured welding cycle of the Gx301 compared to today's is approximately 48%.

6.7 Gx305 and Gx305

The parameter set individually for the original simulation:

- Max time per path planning: 1814400 seconds.

The results from the optimized path with the original sequence:

- Time utilized of the “Max time per path planning”: 354396 seconds
- Total time with both robots and Gx305 tools: 110.437 seconds
  - R8B11 with Gx305: 103.221 seconds
  - R8B12 with Gx305: 108.198 seconds
Figure 6.12 shows the distance to the closest static geometry while the robots perform their paths; green represents the R8B11 robot and blue represents the R8B12 robot. The shortest distance of approximately 1.4 millimetres occurred between the tools and cab at several locations during the welding cycle. The IPS improved the sub welding cycle of the Gx305 with approximately 1\%.

The parameter set individually for the IPS configured simulation:

- Max time per path planning: 90000 seconds.
- Max calculation time: 1814400 seconds.

The results from the optimized path where the IPS load balanced, sequenced and path planned:

- Time utilized of the “Max calculation time”: 28800 seconds.
- Total time with both robots and Gx305/Gx305 combination: 132.991 seconds
  - R8B11 with Gx305: 103.426 seconds
  - R8B12 with Gx305: 104.964 seconds
The graph in figure 6.13 shows the shortest distance measure between a active object and a static geometry. Green graph represents the R8B11 robot and the blue represents the R8B12 robot. As in the previous simulation, the shortest distance measure occurred at several location; the distance was approximately 1.4 millimetres. The welding cycle time of the IPS configured sequence increased with approximately 20% instead of minimizing.

6.8 Total welding cycle
The original welding cycle contains four different welding tools combinations and with the twelve results of sub welding cycles presented above a combination into 3 different cases can be presented. These cases can be seen in Appendix B as well as compiled matrix with the results from every simulation in Appendix C

6.9 Enterprise Architect
The work method described in Enterprise Architect provides a easier introduction into the functions of the IPS software. The description is outlined in a step by step vision which the user can follow as the work is conducted. The schematics of the work method in Enterprise Architect can be followed in Appendix D
7 Error assessment

In this chapter, all geometries and operations that could or might have caused a deviation to the results are presented. Explanations to why geometries are excluded are also discussed.

The front fixture in the original station had two more operations besides holding the front wall at place. The fixture had to hold the roof frame to the front wall with a clamp until the first spot was welded and thereafter release the clamp. Second operation was to raise the strengthening beam up to the top of the front wall and hold it there until it was welded together. These operations were not performed since the front fixture in the IPS did not contain any kinematic data therefore a correct time frame could not be retrieved in the sub weld cycle of the Gc007/Gc008.

The exact positions of the weld spots were retrieved from Delmia; the P19 cab model. The tolerances of the P19 cab model is automatically changed a little when converting .cgr to .wrl thereby moving the positions of the weld spots compared to the locations in Delmia. This altercation is minimal; approximately ±2 mm at most.

Weld spots locations might have been altered automatically, when converting general features to weld spots, the spot tends to seek to the surface of the closest sheet metal. Therefore, the location of the weld spots might have shifted a tenth of a millimeter at most. These observations are targeted at the weld spots in the verification tests and the simulations.

The IPS could not manage joint dependence therefore a decision was taken, to remove unnecessary objects on the robot that might slow down the calculation process while simulating. Parts such as the balance weight and hydraulics on the robot were thought to be unnecessary. As the project progressed, an observation was made on the clearance between the balance weight and the fixture table holding the roof; the observation was made on the real world station. The chance of the balance weight colliding with the fixture table was very small but should still be taken into consideration.


8 Discussion

In this chapter, the results are discussed and validated with the information found in Theory chapter.

One of the decisive parameters that had a great impact on the cycle time was the weld time, set to consistent number of 1 second; given by the Oskarshamn production personnel. Looking at the Gc001 welding cycle, the improvement was approximately 34 % which is rather high but considering that 1 seconds was the number presented by the Oskarshamn production personnel and the information found in the Theory chapter, 1 second would be an appropriate number for weld time. According to the information, electrodes with diameter of 14 mm and sheet metal thickness of 4-5 mm requires a weld time of approximately 1.4 seconds. In this case the electrodes are 16 mm with sheet metal thickness of 4-5mm an appropriate weld time would therefore be approximately 1 second since the sheet metal thickness is the same but the electrode diameter is larger.

In the case of the Gc007/Gc008 welding cycle, the first sub welding cycle in the station. A couple of other operations were performed which could not be simulated in the IPS, therefore these operations as well as time for these operations were not considered. Due to the other operations 2 wait positions per robot existed in the original sequence, these on the other hand were considered and implemented into the sequence in the IPS. The issue appeared when a load balance and sequence simulation was created, since the IPS considers every coordinate as a location that the TCP of the tool must visit. When the IPS plans the sequence, it plans either after the most or first optimized path depending on the “Minimum gap to optimum solution” parameter and therefore does not consider the wait positions order in the sequence which has to occur simultaneously by the two robots. Consequently, the IPS configured “load balance and sequence” simulation for the first sub welding cycle cannot be considered in the results, this conclusion involves the Gc007/Gc001 combination as well. Another issue with the first sub welding cycle was the first five weld spots joining the front wall to the floor; weld operation performed by the Gc007 on the R8B11. The IPS has never before been tested to solve problems where the access of the weld spots are too tight, therefore these five weld spots were discarded from the simulations. As a result, the first sub welding cycle were only performed on 12 weld spots and compared to the time frame for these 12 weld spots.

In the case of the Gx305 tools welding cycle, the IPS configured “load balance and sequence” simulation showed a increase in welding cycle time. One conclusion is that the IPS calculates with the given orientation of the weld spots and does not alter the Z-orientation to gain better weld cycle time. Therefore a research should be performed within this area; see future work chapter. The weld time in the original station utilizes an adaptive system that notice when the correct resistance is reached and thereby finishes the weld spot. This can be a contributing factor since the IPS uses a consistent number for the welding time parameter. The simulation based on the original sequence showed a slightly better cycle time by approximately 1 %. Hence, the optimization of the Gx305 welding cycle is as optimized as possible according to the IPS.
In the case of the Gx301 welding cycle, the original sequence showed a slightly better improvement than the IPS configured optimization. Difference between these two were the load balancing where the IPS configured had all weld spots evenly distributed to the two robots while in the original the R8B12 robots has two more weld spot than the R8B11 robot.

For the Gc001 tools welding cycle, the time recovered from the virtual world compared to the real world showed an approximate improvement of 34% while performing the same sequence; only difference was the orientation of the weld spots. When the Gc007/Gc008 tools was used in the Gc001 welding cycle the improvement reduced to 27%. This results in the question of which case would bring the most profit, either reducing 2 tools from the station and at the same time reducing the improvement with 7 % or keeping the Gc001 tools and gain a higher weld cycle improvement.

To gain a view over the total welding cycle, four sub welding cycles, each containing different tool combination, were put together. Since two more tool combinations were found, two more cases were put together in addition to the original; one case where two tools are excluded and the other with one tool excluded. Hence, a total of 12 sub welding cycles were simulated and assembled into three different cases; Original, Case 1 and Case 2. The Original case showed most improvement while the other two cases showed slightly less improvement by 1-2 %. The improvement of the Original case were 27 % which can be compared to the thesis performed at Saab; improvement of their welding cycle were approximately 20 %. This verifies that advantages of utilizing mathematical algorithms to obtain better results exists.

The sidetracked assignment during this thesis, Verification test on welding tools and spots, presented two more cases; case1 and case 2. If cost is the main priority case 2 would the appropriate choice since the welding cycle time differs only 2 % to the case with highest improvement, the original case. Since this thesis only included the P19 cab, the cases were also only based on the P19 cab and consequently the tool reductions are based on the P19 cab. However, the results still delivers a vision of what the IPS also could be utilized for; necessary tools for the a certain welding operation.

To summarize, the simulations based on the Original sequence showed the highest improvement among the three cases. However, since the total welding cycle were divided into 4 separate sub welding cycle a pick and combine is possible. By choosing the sub welding cycles with the highest improvement for each stage in welding cycle and thereby obtaining a better result than the three cases that is presented in this thesis.

The drawback with the IPS for welding operation at this stage is the lack of a robot library and therefore each robot have to be configured manually. Another drawback is the export function to other software such as data in the form of TCP movements or robot codes cannot be exported, and therefore no real world trial were able to be performed. Consequently, all comparisons were made between real world and virtual world since the Original weld cycle used today does not exist in the virtual world due to online optimizations. This kind of comparison might not be as accurate as comparing two real world welding cycles, therefore a future work has to be considered in this area as well.
As the work process is divided into steps in Enterprise Architect with an overlook on each process, the users can easily move back and forth between steps and implement new activities. Thereby creating a new work process that will fit the users purposes.
9 **Conclusions and Future work**

In this chapter, the conclusion of the results are drawn and operations in IPS to improve the welding cycles of station 50 for the p19 cab are presented.

9.1 **Conclusions**

Considering the time spent on offline programming, the original sequence as well as the time spent on improving the welding cycle of station 50 during its existence and comparing that time with the time utilized during this thesis. The time spent on the original welding cycle is significantly larger than the time utilized by the IPS to perform the same sequence as well as load balancing and creating other sequences. Except for the significant reduction in planning time, the IPS delivered a improvement of the same sequence used in the original welding cycle. The improvement raises when the IPS is allowed the opportunity to utilize the load balance and sequence function. The results provides evidence that computerized mathematical algorithms not only simplifies the work process compared to manually online-programming but also optimizes the weld cycle. Besides the optimization of the welding cycle, the verification phase allows the user to manually improve by e.g. checking weld tools utilization, within the IPS. Since the focus of this thesis was to optimize the welding cycle of station 50 for the P19 cab which leads to a faster production and consequently lower costs or more profit. Therefore, the verification tests on the tools creates a valid point in this thesis even though it was not the main goal. Without the possibility to export the robot motions into correct robot codes and implementing the robot codes into real robots, there is no telling of how accurate the results are of the optimized welding cycles.

With the work method description outlined in Sparx systems support tool; Enterprise Architect, an easier “how to” manual for the first time users exists. The layout of IPS 2.0 is as simple as it can get, with all available functionalities presented in the main window. Together with the work method description even a beginner within the virtual field would be able to create simulations in the IPS.

9.2 **Future work**

The verification tests performed before all the simulations presented that the welding tools managed to reach more weld spots than the ones assigned; the weld spots found in the robot program code. With those findings, simulations could be created with other weld spots collection for each tool; compiled from the list found in Appendix A.

All simulations conducted during this thesis are based on “Minimum gap to optimum solution” at 1 i.e. the IPS selected the first optimized solution it could find which might not be the most optimized path. The first successful sequence the IPS finds could be the most optimized but there is no certainty that it is the most optimized path unless a new simulation is created with this parameter set to 0. Therefore, simulations based on “Minimum gap to optimum solution” at 0 would be appropriate to test in the future.

The orientation of each weld spots was manually configured; therefore an extensive research can be made in this area. The orientation of the weld spots were currently angled in a way for
the Z-axis to be close to the normal vector of the sheet metal since the ideal situation is when the electrodes distribute an equal force on the entire weld spots area. In the original station 50 case the Z-axis does not have the exact orientation as the normal vector and thereby experiments can be made by changing the orientation with approximately minor margins to obtain the most optimum welding cycle.

While looking at the verification test, a research where tools exchange weld spots can be performed. With the weld tools welding different weld spots new sequences can be discovered and thereby a faster cycle time might be found.
10 References


3]


[Accessed 26 November 2012].

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### Appendix A – Verification test

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## Appendix B – Different cases

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## Appendix C – Schematic of the results

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<th>Improvement (OII – O)</th>
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