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Optimizing the shipbuilding layout of Damex Shipbuilding and Engineering for cost efficiency

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Cover figure : Picture of the location of Damex Shipbuilding & Engineering (Damen database) and its activities

CONTACT PAGE

Thesis for the degree of MSc in Marine Technology in the specialization of *Ship Production*

Optimizing the shipbuilding layout of Damex Shipbuilding and Engineering for cost efficiency

By

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Performed at

Damen Shipyards Gorinchem

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PREFACE

This report is written by Bas Damman, student at the Delft University of Technology as final part of the Master of Science track in Maritime Technology with the specialization Ship Production. This graduation project counts for 45 ECTS. Execution of this project is done in collaboration with the company Damen Shipyards in Gorinchem and the Delft University of Technology.

The topic of this thesis is “Optimizing the shipbuilding layout of Damex Shipbuilding and Engineering for cost efficiency”. Damex Shipbuilding and Engineering is one of the foreign shipyards of the Damen Shipyards Group. During this graduation project I became very fond of the company’s business, culture and colleagues. With my Ship Production background I got the opportunity to participate in the production process improvement department at the head office in Gorinchem. During this time I was able to greatly enhance my knowledge about shipbuilding. Thanks to connections within the company I was able to visit several other Dutch ship production companies like Damen Schelde Naval Shipbuilding, IHC Metallix and IHC Piping.

To check this gained theoretical knowledge in practice, I got the opportunity to go to Cuba in person and stay at Damex for a month to gather information. This was an experience to remember for a long time. I have made a lot of pictures, some of which are shown in this report (those without a source).

I would like to thank my graduation committee consisting of prof. J.J. Hopman, ir. J.F.J. Pruyn, ir. W. van den Bos and ir. J.B.B. Teuben for their guidance and critical notes. I also would like to thank Damen and its employees, in particular Jack Teuben, Reinoud van der Reijden, Isidro Campos Castro, Ruud Kentie, Jeroen Kossen and Arvid Duijzer for their help, and colleague graduation student Jos Kooij for letting me use his data. And a special thanks is for my friends and family for their support.

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Bastiaan Jacobus Damman

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EXECUTIVE SUMMARY

Damen Shipyard Group (DSG) is a shipbuilding group that builds a large variety of ships at a great number of shipyards. These shipyards are strategically located around the world in a various countries. In 2012 the Damen Shipyard Group had a turnover of € 1,7 billion. One of the foreign DSG shipyards is Damex Shipbuilding and Engineering in Santiago de Cuba (Damex). The shipyard builds ships for the Tugs, Workboats, High Speed Crafts and Fast Ferries product groups of Damen Shipyards Gorinchem (DSGo).

The main advantages of a shipyard on Cuba is the access to South-American markets and the low wages. However, there also are some downsides of this location. A non-Cuban company cannot own Cuban property or a Cuban company. Damex rents property, workers and equipment from Astor, a Cuban state company. This construction contains the risk that the Cuban government can nationalize the company, and DSG loses its investments.

At Damex the following problems are determined: the cost price per ship is too high, the production capacity of the shipyard is too low and the throughput time of the ships is too long. From this can be concluded that Damex has a productivity problem.

These problems are translated in the following targets:

- Damex annual production capacity must be increased by at least 50%
- For investments the annual internal rate of return must have a minimum of 12% over 15 years
- Net present value of the investment, with an annual discount rate of 12%, must become positive over 15 years

The targets are limited by the following constraints:

- The capacity is calculated by using the current product portfolio
- The number of employees (and thus annual man-hours) is constant
- A lower investment is preferred in this research

Investigated is whether it is possible and what it takes to increase production by 200%. Another improvement can be that steel parts processing is done fully in-house instead of outsourcing it to the Netherlands. This cost reducing scenario is investigated in an investment analysis.

To solve the problem and achieve the targets the following main research question is derived: *What is an optimal yard layout regarding cost efficiency for Damex Shipbuilding and Engineering, Santiago de Cuba?*

To answer this question, first a process model is developed that has Damex modeled into a system according to the Delft Systems Approach. The used system consists of a process and its required resources, and the input materials and output products flow.

First the input materials and output products flow is determined by setting a ship, or product mix, following the current order portfolio. Damex builds ships for several DSGo product groups, hence the product mix. The ship mix consists of the Stan Tug 2208; the Stan Patrol 4207 and the Stan Lander 5612 ships. Since the number of employees is set constant, the current annual ship production capacity is: 5 Stan Tug 2208 ships, 3 Stan Patrol 4207 ships or 2 Stan Lander 5612 ships. As product scenarios the extremes are used, which means that only one ship type is used per product scenario.

To determine the input materials and output products flow, the ship is divided in intermediate products which are produced during the various stages of the shipbuilding process. To perform these workloads, resources are required. Products can be produced by different methods, which require different resources.

Of the overall shipbuilding processes, the ship assembly and steel part processing are investigated. The ship assembly is the actual value adding process of the shipyard, and productivity can be improved here. The steel part processing is investigated to determine the feasibility of steel part processing at Damex or outsourcing it in the Netherlands, since part processing is much cheaper at Damex.

Ship assembly productivity can be improved by:

- Having the ship assembly processes organized in such a way that there is as little non value adding time as possible
- Intermediate products are as advanced as possible before ship erection at the slipway
- Mechanization of ship assembly processes
- Workers are skilled and specialized in the assembly of certain (intermediate) products

Of all these different methods, several production method scenarios are made. These scenarios produce the three different ship scenarios. A computerized calculation model is created to give assistance for the many calculations. For all three ship types and for all production method scenarios the reduced man-hours are calculated. For each production method scenario that reduce the costs of the ship, in man-hours and therefore also money, the production capacity is increased. Given the constant annual man-hours at Damex and the variable other resources, the new capacity is increased by the inverse of the man-hour reduction per ship.

Because of increased productivity, the throughput time of the ships is reduced, which reduces financing costs. When production is increased, annual overhead costs can be divided over more products which makes the product cheaper.

To achieve this state of productivity, investments are required for acquiring capital goods. When the sales price of the products remain the same, the extra cash flow generated from the cost reductions is used to earn back the investments. The scenarios that meet the production increase targets are identified and molded into concepts. The required investments for new capital goods of the concepts that meet the targets are assessed for the internal rate of return and net present value targets. Of the concepts that meet all targets, the cheapest is selected in accordance to the design constraints.

Under the current assumptions, the concept that meets all targets and requirements is the maximum section outfit concept. In this concept panel building. section building and hot outfitting are done during section building inside a hall, by using sufficient cranes and transport machines. Section conservation and maximum outfitting are subsequently done in a separate hall. These outfitted and painted sections are transported to the slipway hall by a section transporter. There the ship is erected, further outfitted and launched. After the launch it is finished at the outfitting quay.

This concept requires an investment of €4 191 100,- and causes a production increase of 71,6%. The internal rate of return over 15 years is 14%, and the net present value is €430 000.

In-house steel parts processing is a good investment when the previously mentioned concept is implemented. In-house steel parts processing does not increase production, but costs are reduced. In-house steel parts processing requires an investment of €1 234 0000,-. Internal rate of return is 14% and the net present value is €220 000,-.

A production increase of 200% is possible, but not when the current workforce is constant. When this increase is implemented, the workforce must be increased by 71,6%. There is sufficient area at the shipyard, but one large, or multiple new smaller halls have to be built.

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LIST OF DEFINITIONS

Advancement of interim product	Quantity of parts (for example outfit) already assembled into an interim product before slipway processes
Capital goods	Durable goods (machines) that are used for production of goods
Casco	Structural and buoyant cohesion of ship
Cold outfitting	Outfit that can be mounted without welding
Efficiency	New sacrifices compared to old sacrifices in producing the same product
Hot outfitting	Outfit that can be mounted effectively only by welding
Intermediate product	Product of assembly process, but not end product
Internal Rate of Return of investment (IRR)	The annualized effective compounded return rate of an investment. When the NPV equals 0 this rate is calculated: $NPV = \sum_{t=0}^{T} \frac{C_t}{(1+IRR)^t} = 0$
Investment analysis	An investment is an expenditure with the goal to increase future cash flow. In an investment analysis the expenditure is compared to the future cash flow.
Man-hour tariff	A man-hour tariff indicates the total costs of letting one worker work for an hour. This includes direct and indirect costs.
Net Present Value of investment (NPV)	Difference between the present value of future cash inflows (C_t) and current cash outflow (C_0; investment). $NPV = \sum_{t=1}^{T} \frac{C_t}{(1+r)^t} - C_0$
Non value adding time	Time in which no (intermediate) product is produced during production time.
Process	A process is a series of transformations that occur during throughput which result in a change of the input elements in place, position, form, size, function, property or any other characteristic
Production capacity	The maximum number of products that can be produced per year
Productivity	Number that compares products (or output) and sacrifices (input)
System (of production processes)	A collection of processes within a system boundary. The processes have mutual, and outside relationships.
Throughput	Number of products produced per year
Yard layout	The whole productive layout, including all capital goods like facilities and main equipment. Tooling is not considered a facility

LIST OF ABBREVIATIONS

CNC	Computer Numerical Control
CYS	Contracting and Yard Support
Damex	Damex Shipbuilding and Engineering
DSA	Delft Systems Approach
DSG	Damen Shipyards Group
DSGo	Damen Shipyards Gorinchem
DSGa	Damen Shipyards Galatz
DSNS	Damen Schelde Naval Shipbuilding
DTC	Damen Technical Cooperation
IDK	Integraal Dekkende Kostprijs
IRR	Internal Rate of Return
NPV	Net Present Value
OECD	Organization for Economic Cooperation and Development
PROPER	Process Performance
SAW	Submerged Arc Welding
SLa5612	Stan Lander 5612
SPa4207	Stan Patrol 4207
STu2208	Stan Tug 2208
WBS	Work Breakdown Structure
WIP	Work in Progress
YS	Yard Support

1 INTRODUCTION

In this chapter the research is introduced. First there is an introduction of the company and of the concerning shipyard. After that the reasons for this research are explained. The problem is analyzed and design targets and constraints are set. In order to investigate how to achieve the targets, research questions are established. After that the scope of research is defined. Finally an overview of the report is given.

1.1 Introduction of company and shipyard

In this section first the principal company is introduced: Damen Shipyards Gorinchem (DSGo). The main difference between the traditional shipbuilding process and the Damen process is explained. After that the development of DSGo into a multinational company and the origination of the Contracting and Yard Support (CYS) department is described. Finally the concerning shipyard for this research, Damex Shipbuilding and Engineering, is introduced.

1.1.1 Damen Shipyards Group

Damen Shipyard Group (DSG) is a shipbuilding group that builds a large variety of ships at a great number of shipyards. These shipyards are strategically located around the world in a various countries. In 2012 the Damen Shipyard Group had a turnover of € 1.7 billion [Damen website, www.damen.com].

DSG originated from the Damen shipyard in Hardinxveld, and later in Gorinchem in the Netherlands. Damen originally was specialized in building small ships like tugs and small workboats. Due to good results, Damen was able to expand its activities and acquire other specialities and shipyards. Today Damen's product mix ranges from the original tugs and workboats to high speed crafts, fast ferries, cargo vessels, fishing vessels, dredging vessels, offshore vessels, mega yachts and naval ships. There is also a large ship repair division, and a services division. In this way Damen can facilitate a lifelong support of its ships.

1.1.2 General Damen Shipyards shipbuilding process description

There is a difference between the standard way of shipbuilding and the Damen way of shipbuilding. Both ways are stated below.

A regular Western European, North American or East Asian shipyard builds ships in the following way. [3, 4, 5]

Figure 1. Regular shipbuilding process

Damen Shipyards builds ships in a slightly different way. Damen has developed a strategy to use strategically stocked casco's (bare ship hull and superstructure) of standard designs to significantly reduce the delivery time. This way the design and casco building stage are done before the signing of the contract. The sales force aggressively sells these standardized products. Also after delivery the maintenance and emergency repairs can be done by Damen personnel, which contributes greatly to customer satisfaction.

Figure 2. Damen shipbuilding process

There is however a difference between Dutch and foreign Damen shipyards. The entire Damen process is only applied at the shipyards in the Netherlands. The cascos can be built at internal foreign yards, or are ordered externally. The standard designs are engineered for the specific yard's facilities and/or customer specifications.

1.1.3 Damen Shipyard Gorinchem and CYS – Yard Support

Damen Shipyard Gorinchem (DSGo) is the head office of the group. Originally it was the main shipbuilding location of Damen. Because of the many acquisitions, foreign and domestic, this has changed. But DSGo, alongside its head office function, is still one of the main shipbuilding locations of the group. DSGo's current production is mainly the outfitting of high speed crafts, tugs and workboats.

Because of the enormous growth of the company, and its many foreign acquisitions, the Contracting and Yard Support (CYS) department was created. This department has the task to manage the contracts between DSGo and the foreign building yards. Also it has to streamline the building orders and production over the yards (portfolio management), and closely monitor the efficiency of the yards. When required by the board or individual shipyards, Yard Support (YS) can provide consultancy services to the shipyards for productivity and efficiency gains.

1.1.4 Damex Shipbuilding and Engineering

One of the foreign DSG shipyards is Damex Shipbuilding and Engineering in Santiago de Cuba (Damex). Damex was established in 1995. The shipyard builds ships of Tugs, Workboats, High Speed Crafts and Fast Ferries product group designs of Damen Shipyards Gorinchem (DSGo). Damex is part of the Damen family because of its strategic location and market access. Damex is centrally located in the Caribbean, and provides access to the rapidly developing South-American markets. Furthermore the Cuban wages are low, which means low ship construction costs. At Damex, in 2011 the total number of employees was 170. At the end of 2012 this number grew to 180.

However there are some downsides of this location. Cuba is a communistic country and has other laws and regulations than Western capitalistic countries. A non-Cuban company cannot own Cuban property or a Cuban company. Therefore Damex is a joint venture between Damen and the Cuban government shipbuilding company Astor. Damex rents property, workers and equipment from Astor. When investments are required for Damex, DSG will pre-finance it and Damex will pay it back in terms. This construction contains the risk that the Cuban government can nationalize the company, and doesn't pay back the pre-financing of DSG. On the other hand, Damex delivers a steady job source and a steady stream of international currency for Cuba [I. Campos Castro, Yard Manager Damex].

Because of the US trade embargo, and therefore scarcity of goods in Cuba, all material and equipment for the new building ships, and new production facilities and equipment, are to be imported by DSG. The Damen Technical Cooperation (DTC) product group is experienced in supplying foreign external shipyards with materials, equipment, designs and project management, and therefore manages the shipbuilding projects for Damex. Availability of (working) processing machines and installations at the Damex yard, determines the amount of steel part processing of materials that is done at other locations [J. Kossen, DTC Project Manager].

1.2 Reasons for this research

In this section the reasons for this research are stated. Damex experiences productivity problems. Damex management has asked DSGo's CYS – YS department to make a plan to improve and optimize their yard's production processes and facilities. These problems are described in this section.

1.2.1 Problems of company

In recent years the Damex yard is experiencing a decrease in productivity. The decrease of productivity causes late deliveries of ships. A decrease in productivity is the same as an increase in building costs per ship in man-hours. Man-hours cost money, which means that costs per product, both in man-hours and money, have increased in a too rapid rate.

There are several new building orders, and therefore a capacity problem could arise. The production capacity is too low for current new building orders, and for big potential orders.

At Damex the following problems are determined:

- The cost price [8] per ship in man-hours is too high compared to other comparable foreign DSGo shipyards
- The production throughput time per ship is too high compared to western shipyards
- Production capacity per year is too low compared to other comparable foreign DSGo shipyards

The cost price of a product is the total amount of effort or money it costs the producer to produce the product. The production capacity is the number of ships that can be built per year. The production throughput time is the time it takes to manufacture one product.

In order to increase productivity, processes have to be improved. To realize such a transformation, investments in the shipyard are required. Investments have to be earned back by the extra cash flow generated by these investments.

1.2.2 Goals of investments in Damex

Damex builds different kinds of ships. Therefore the currently used method of measuring production capacity is the number of tons of steel per year. Currently Damex has a steel production capacity of roughly 600-700 tons per year. This number corresponds with 5 Stan Tug 2208 or 2 Stan Lander 5612 ships [J. Kossen]. DSGo and the Damex management [I. Campos Castro] like to see this increased to roughly 1000 tons per year, which is an increase of 50%. CYS thinks 2000 tons per year is possible when sufficient investments are done [J.J.B. Teuben, Project Manager Yard Support]. This means a throughput increase of 200%.

1.2.3 Research considerations

There is a plan of the Damex management to remove several old buildings to make room for new ones. This way a more or less green field (no existing buildings) situation is made, except for the existing ship erection and outfitting hall, the current repair slipway and the office/warehouse building. The general plan for this is in figure 29. The Damen Civil Services Special Projects department is currently building a new slipway in the ship erection and outfitting hall. This department can also construct the possible new halls [A. Duijzer, Civil Services Special Project Manager].

More production capacity can be achieved by hiring more workers. However, shipbuilding is not a really popular source of employment in Santiago de Cuba, since young people rather work in the tourist business. For this reason Damex has great difficulty in hiring new skilled and motivated workers. When production capacity can only grow by hiring new workers, growth will be very slow [R. Kentie, Damex Shipbuilding Coordinator]. Therefore the number of employees at Damex can be considered constant for this research.

To reduce the cost price of a ship and increase production capacity, processes have to be changed and the layout rearranged. An optimal *yard layout* has to be determined for Damex. Yard layout in this thesis means <u>the whole process layout, including facilities and main equipment</u>. Tooling (tools handled by workers such as welding equipment, grinding tools etc.) is not considered in this research.

It is very unlikely that banks are willing to finance investments in Cuba. Investments in Damex have always been done by using DSG capital. It is assumed this will remain the same.

Production must go on while the new facilities are being constructed. Therefore not every investment can be done in the same time, so an investment plan is to be made.

1.3 Problem analysis

In this section first the structure of this research is explained. After that the productivity and production capacity problems are analyzed. Investment requirements and cash flow are analyzed. After that Damex' influence on the cost price of building a ship is analyzed. An overview is made on how to reduce these costs and thus generate an additional cash flow.

1.3.1 Research structure

This graduation is structured as the operations research method stated in Hillier [30]:

1) Define the problem of interest and gather relevant data
2) Formulate a mathematical model to represent the problem (i.e. design targets and constraints)
3) Develop a computer-based procedure for deriving solutions to the problem from the model
4) Test the model and refine it as needed
5) Apply the model

The problem of interest has been established in 1.2. In 1.3 the problem is analyzed and a mathematical model is formulated in 1.4 to represent the problem. From chapter 2 to 9 the computer-based model is developed (and tested and refined). In chapter 10 and 11 the model is applied.

1.3.2 Productivity analysis

As stated in 1.2 Damex has a productivity problem. A productivity reduction has been experienced at Damex and therefore late deliveries of ships. This means that throughput time has been increased because of productivity reduction. This also means that when productivity is increased, throughput time decreases.

Productivity is measured by: $$productivity = \frac{output}{input} \text{ [2]}$$

Or: $$productivity = \frac{results}{sacrifice} \text{ [1]}$$

When the new annual production is to be increased (results, output) and annual man-hours is to remain the same (sacrifices, input), productivity is increased. But it can also mean that the same amount of ships can be built by less workers per year.

When using constant result or output (same quality and quantity of product), efficiency per product is measured by comparing the previous sacrifices per product to the current, or the current productivity to the previous: A reduction in costs, or sacrifice, with the same quality and quantity of products means an increase in efficiency for the same product [1].

$$If\ result\ is\ constant:\ \ efficiency = \frac{productivity_1}{productivity_0} = \frac{sacrifice_0}{sacrifice_1} \text{ [1]}$$

From this analysis can be concluded that: When productivity is increased, sacrifices (man-hours, money) and throughput time per product are reduced. When sacrifices per product are reduced and the same amount of resources remain available, more products can be built, which means capacity is increased.

1.3.3 Production capacity analysis

As stated in 1.2, the number of tons of steel per year has to be increased by 50%, and if possible by 200%. However, the use of tons of steel per year has several flaws. The method assumes products of the same level of complexity and plate thickness. Also it excludes the amount of outfit. A better way to establish the shipyard's throughput is to work with compensated gross tonnage (CGT) [9, 18]. Unfortunately it is very difficult to establish the different coefficients of the current production portfolio, since the ships are too specialized to be covered in the OECD report.

Therefore the number of ships per year is used, based on the number of direct man-hours per ship and the fixed current available man-hours.

1.3.4 Investments and cash flow analysis

Investments are meant to generate additional cash flow for the company. Additional annual cash flow is generated when annual expenditures are reduced, when more products are built and sold, or a combination. To test the amount of the additional cash flow, investments evaluation tools are used. The required investments are tested by the investment evaluation tools stated in Heezen [8]: Internal Rate of Return (IRR) and Net Present Value (NPV). Damen uses an annual discount rate of 12% [R. van der Reijden, Business Process Manager Yard Support].

These two tools essentially follow the same principle (discounted cash flow), but internal rate of return shows the future profitability of the investment, while the net present value shows the current value of future profit. Both are dependent on a time span. For this research the time span of 15 years is chosen, since it is the lifespan of most capital goods at a shipyard [32].

Damex is located on Cuba. A big disadvantage of Cuba is the investment risk: investments in Cuba stay in Cuba and cannot be sold. The ultimate decision whether to invest or not is for the company.

1.3.5 Local influence over ship cost price

In order to generate cash flow to earn back the investment, the ship cost price has to be reduced. The cost price of a product is the total amount of sacrifices (usually money) it costs the producer to produce the product. The Integral Covering Cost Price (Integraal Dekkende Kostprijs; IDK) is determined by the costs of DSGo, and the local building costs (Damex).

The used cost breakdown is following the direct costing method [7]. Costs (both DSGo and local costs) can be divided between direct and indirect costs. Direct costs have a causal relation with the creation of the product. This relation is to be established in an economically sound way. Examples are costs of materials and labour costs.

Indirect costs do not have a causal relation with the creation of the product, or when the causal relation cannot be established in an economically sound way. Depreciation costs of machines are indirect costs. Or for example there is a causal relation between energy use and the creation of a product. But it is hard to say how much energy is used per individual product when different products are produced at the same time. Also it is not really important to know since the payments are done monthly and not per product. Therefore energy is seen as indirect costs.

Most direct DSGo costs (e.g. project management) are not influencable for Damex. Materials and equipment are purchased centrally by DSGo Procurement. Financing of the materials and equipment, which is also done by DSGo for Damex, is time dependent and an annual interest of 7% has to be paid [29]. This time is influencable, which makes the financing costs influencable for Damex. Most indirect costs (sales, engineering etc.) are also made at DSGo, but are not infuencable for Damex.

The local building costs must cover the expenses made by the shipyard. The direct labour costs are influencable for Damex. Indirect costs (e.g. overhead labour costs, energy costs, depreciation of local investments) are also influencable, since they are distributed over the number of produced products.

The cost structure shown in figure 3 shows the subdivided influencable cost price per ship.

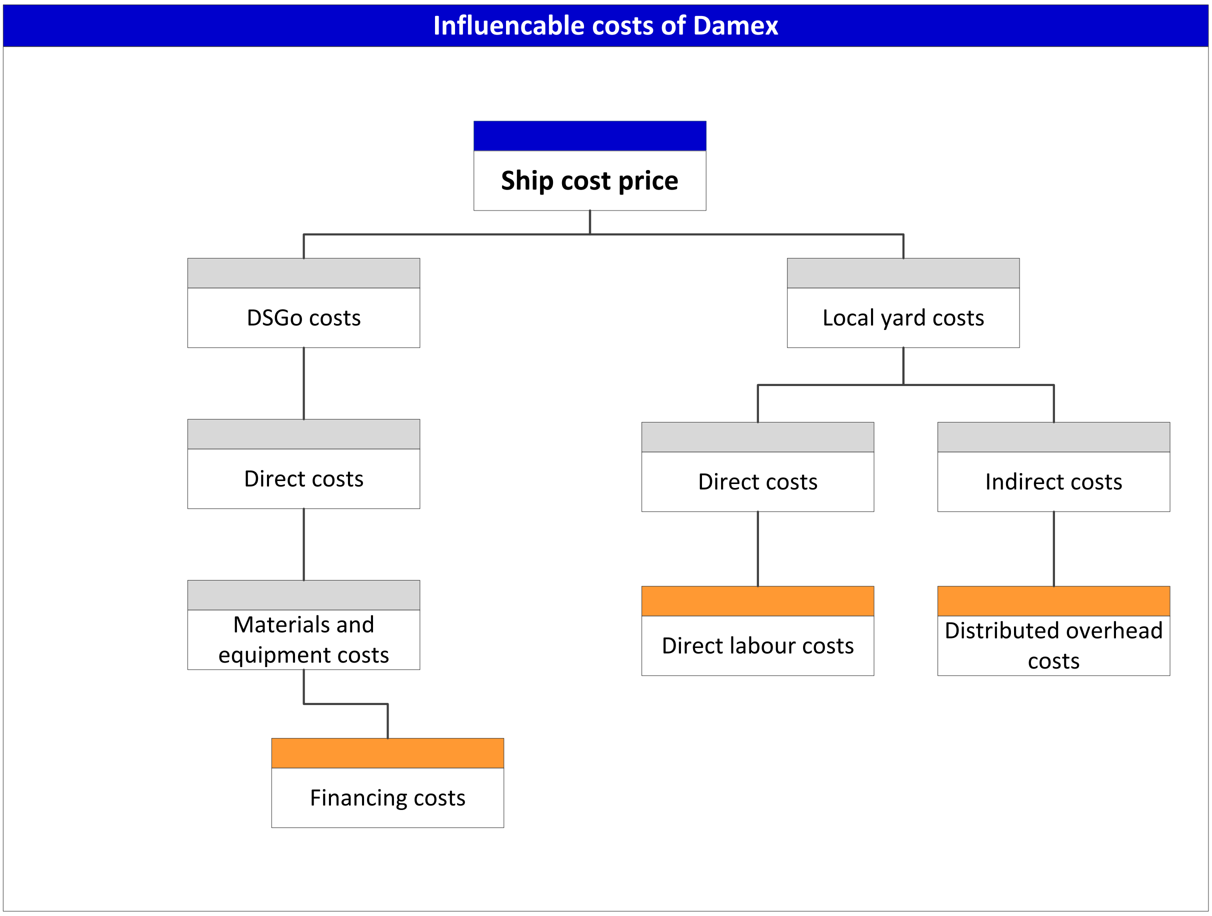

Figure 3. Influencable costs of Damex

1.3.6 Cost reduction options

All the options below are true when the sale price is constant.

For financing the materials and equipment an annual interest of 7% [29] must be paid. A reduction in throughput time results in less financing costs since the time over which interest is to be paid is reduced. Whether Damex, Damen or the customer pays the financing costs of the materials and equipment does not matter. These are costs that are made when producing the product, and reduction means more profit for Damen. This means that financing costs per product are a cost component to be taken into account.

Direct labour costs are measured per ship. These costs can decrease when wages are lowered, or when less man-hours are required for producing the same product. Wages are set by the Cuban government, so the man-hours per ship must decrease. Direct labour costs are measured in man-hours. Man-hours are the paid hours in which a man works.

Overhead costs are the local indirect costs measured per year. An example of local indirect costs is the energy cost. The current energy costs are approx. 10% of the integrated man-hour rate; but it is not certain how much these costs will increase. According to the Damex management [I. Campos Castro] these costs will be manageable. The other overhead costs are considered constant. Since the energy cost increase is manageable, the annual overhead costs are considered constant in this research.

When more ships are produced, the annual overhead costs can be divided over more ships. This means less overhead costs per ship.

The cost price of a ship can be decreased by:

- Man-hours per ship reduction
- Dividing local annual overhead costs over more ships by increasing shipyard throughput
- Decrease financing costs by reducing ship throughput time

1.4 Design targets and constraints

As explained in the problem analysis, the productivity and the annual production capacity of Damex must increase, and the throughput time per ship must decrease. Investments in Damex are required for this. In order to formulate the mathematical model to represent the problem, in this paragraph the design targets and constraints are stated.

1.4.1 Deriving design targets

As stated in 1.2, the number of tons of steel per year has to be increased by 50%, and if possible by 200%. However, the use of tons of steel per year has several flaws. Therefore the number of ships per year is used, based on the number of direct man-hours per ship and the fixed current available man-hours.

The required investments are tested by the investment evaluation tools stated in Heezen [8]: Internal Rate of Return (IRR) and Net Present Value (NPV). Damen uses an annual discount rate of 12% [R. van der Reijden].

Production capacity targets:

- Damex annual production capacity must be increased by at least 50%
- For investments the annual internal rate of return must have a minimum of 12% over 15 years
- Net present value of the investment, with an annual discount rate of 12%, must become positive over 15 years

Investigated is whether it is possible and what it takes to increase production by 200%

1.4.2 Setting design constraints

There are several constraints that have to be taken into account.

- The capacity is calculated by using the current product portfolio (described in chapter 3)
- The number of employees (and thus annual man-hours) is constant
- A lower investment is preferred in this research

A production increase constrained by a constant number of employees ensures the increase of productivity. Increase of productivity ensures the reduction of the cost price per ship.

1.5 Research questions

In this research is investigated how the targets, within their constraints, can be achieved. In order to do this a main and secondary research questions are established.

1.5.1 Main research question

The answer for the main research question solves the problem for this research.

What is an optimal yard lay-out regarding cost efficiency for Damex Shipbuilding and Engineering, Santiago de Cuba?

1.5.2 Secondary research questions

In order to answer the main research question, the secondary research questions have to be answered first.

- What (intermediate) products, or workloads, are to be built at Damex? (chapter 3)
- How can a shipyard production process be modeled into a system? (chapter 4, 5)
- What are the resources for the workloads of Damex' sub-processes? (chapter 5)
- How can the resources of Damex' sub-processes be calculated? (chapter 6)
- How can Damex' sub-processes be more productive? (chapter 7)
- How are the shipyard sub-processes' workloads and resources arranged at reference shipyards? (chapter 7)
- What influences do the productivity increasing methods have on the use of Damex' resources? (chapter 10)

1.6 Scope of research

In this section the framework in which this research takes place is set. After that the current conditions which are considered to remain constant are set.

1.6.1 Framework

The subject of optimizing an entire shipyard is a relatively broad research and comprises a great many aspects. The used framework is stated below.

- Considering figure 2 in section 1.1, in this thesis the focus is the <u>production</u> stage.
- The research is done regarding yard layout, which means the whole process layout, including facilities and main equipment, but excluding tools.
- There are the Cuban shipbuilding circumstances which are further explained in chapter 4.
- Engineering and materials are considered to be delivered on time by DSGo.
- Because of the unreliable supply line (explained in chapter 4), every part and drawing of a ship is in stock at Damex <u>before production</u> commences.
- The ship portfolio is considered to contain three different ship types based on the current order portfolio: Stan Tug 2208; Stan Lander 5612; Stan Patrol 4207, which are fully described in chapter 3.

1.6.2 Conditions

Some conditions at Damex are considered permanent, independent of any investments.

- The <u>workforce</u> at Damex is gradually growing, but for this research it is considered <u>constant</u>.
- Ship sales prices remain constant over the years
- Additionally produced ships are sold
- The current <u>one work shift per day</u> is assumed maximum, since the workforce is constant
- Workers work a theoretical 2200 hours per year. They work 50 weeks of 44 hours.
- Investments in capital goods for Damex are paid with own capital, since it is unlikely that banks will invest in Cuba [R. van der Reijden].

1.7 Report overview

In chapter 1 the project is introduced, the problem is explained, further analyzed and specified. The design targets are set and the scope of work is defined. In chapter 2 the methods of systems analysis, process improvement and research validity are explained.

In chapter 3 the ship portfolio (end products) and its intermediate products are analyzed. Ship specific data is analyzed. In chapter 4 the overall shipyard processes are analyzed. In chapter 5 the ship assembly process is broken down into sub-processes and analyzed. Required process resources and existing process improvements are determined. In chapter 6 estimators for predicting the future use of resources are determined.. Production specific data is analyzed.

In chapter 7 scenarios are set to investigate the feasible productivity improvements. The impact of these improvements on Damex' resources are determined by using reference shipyard data. Productivity improvement scenarios are set up to be tested.

In chapter 8 the guidelines for a computer model are stated and in chapter 9 these ship assembly processes are modeled in a calculation model.

In chapter 10 the scenarios are tested for the production increase targets. The scenarios that meet the production increase targets are molded into concepts. These concepts are tested for the investment targets in the investment analysis. The required resources for these concepts are presented in chapter 11. By using the results of these concepts, the investments that meet the investment targets are determined. From this emerges the concept that meets all targets and requirements. Of concept the optimal layout is determined and the investment plan is presented.

The coherence of this report is showed in figure 4.

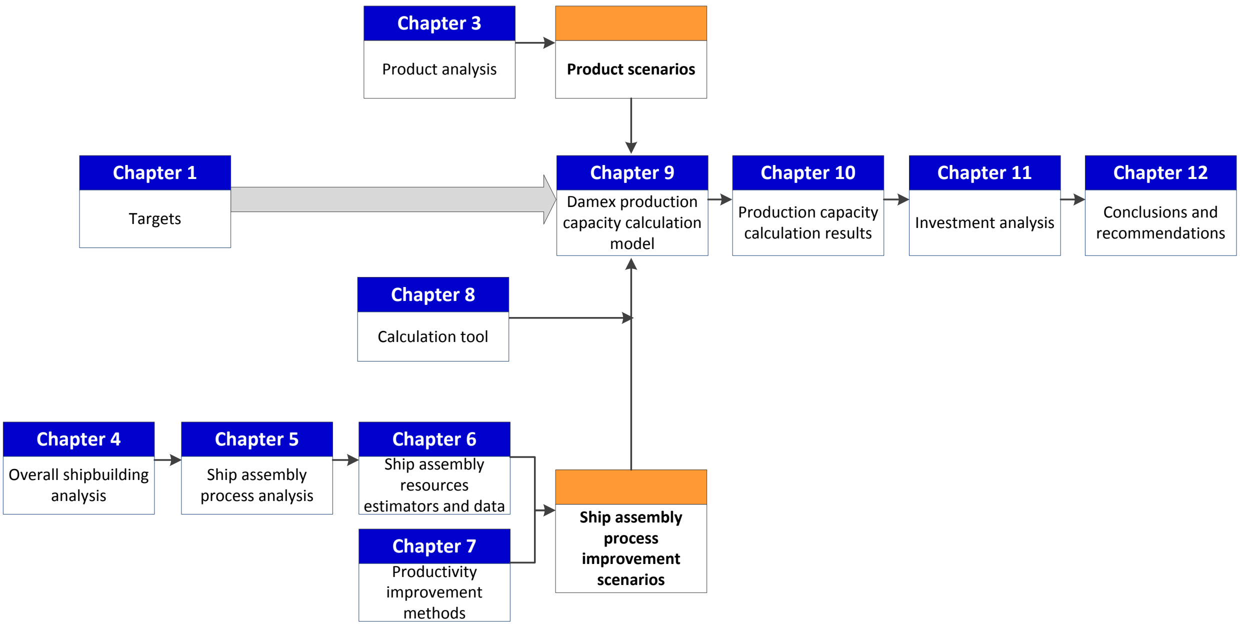

Figure 4. Report coherence

In this picture chapter 2 is not shown, because chapter 2 is used in the entire report.

Figures and photos without a source are own made.

2 METHODS OF ANALYSIS

In this chapter the theoretical approach of this research is elaborated. First the shipyard has to be understood. This can be done by modeling a shipyard into a system [1]. When this is done, productivity improving methods for shipyards can be implemented into the system. To ensure reliability and validity of this research, certain validity standards must be followed.

The method for modeling a shipyard into a system, methods of improving productivity of a shipyard and methods of ensuring validity of process modeling and data are described in this chapter.

2.1 Method of modeling a shipyard into a system

A ship is a complex product with a wide variety of parts that can be assembled by specialized workers in different phases of the production. Different resources are used, during different processes, to handle the (intermediate) products. To make forecasts of the shipyard, it is modeled into a system.

2.1.1 Process analysis

A **process** is *a series of transformations that occur during throughput which result in a change of the input elements in place, position, form, size, function, property or any other characteristic* [1]. A representation of this is shown in figure 5.

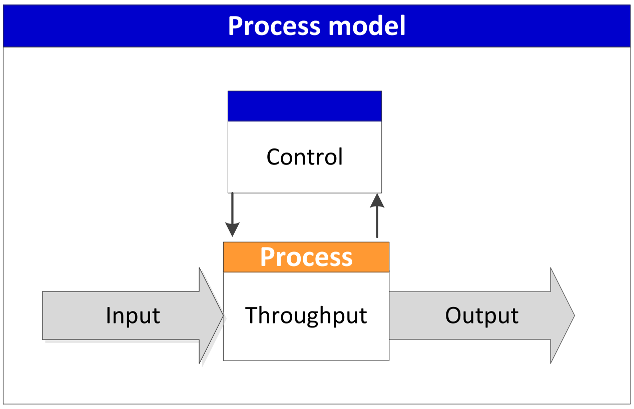

Figure 5. Process model

The control of the transformation process for quality, costs and time constraints is done by the project management of DSGo, which is not included in this research.

PROPER model

In the Delft Systems Approach there is the PROPER (PROcess PERformance) modeling concept. In an industrial process there are the material flow, the resource flow and the information flow [1]. In order to perform a process on the material flow, resources are needed for transforming the material. This is represented in figure 6. In shipbuilding a resource can be labour, a production area, a transport or production machine [3]. Information is needed for the requirements and control of the transformations of the material flow. Information can be planning or drawings. Drawings are considered to be supplied by DSGo, and are therefore not in the scope of this research. The system control process in the PROPER model is not considered in the scope of this research, since project management is performed by DSGo, and is not influenced directly by the investment plan for productivity gain.

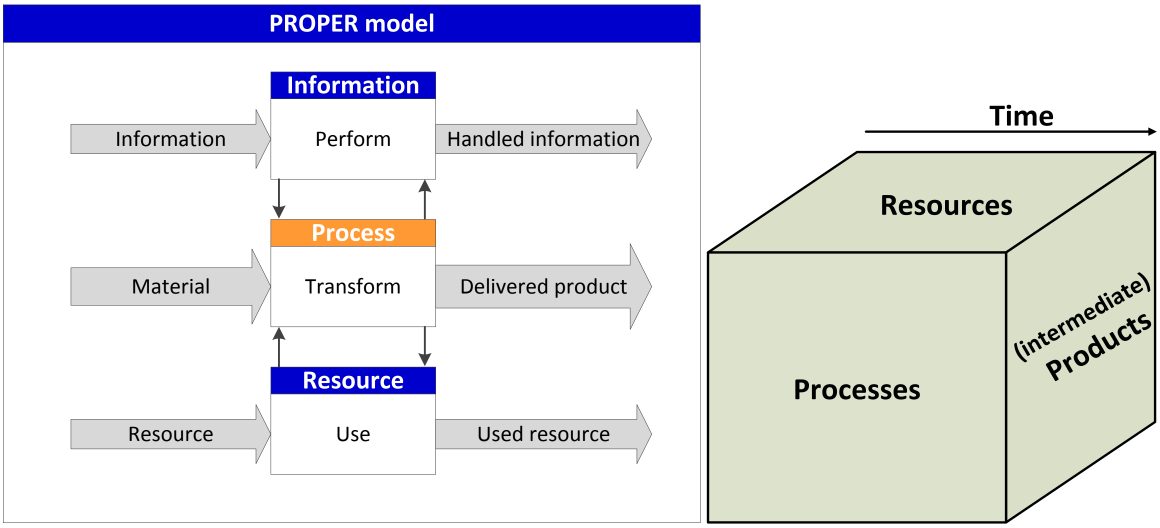

Figure 6. PROPER model and matrix shape model representation

A process model is made of the ship production process. The shipbuilding process can be split in several sub-processes, in which all different product parts are assembled. In the DSA this is represented as the shipbuilding process (2D) black box that is opened and next level boxes appear. The shipyard sub-processes are mapped in this fashion.

The 3D box in figure 6 is a representation of flow of input material and output (intermediate) products over time, and processes using resources over time.

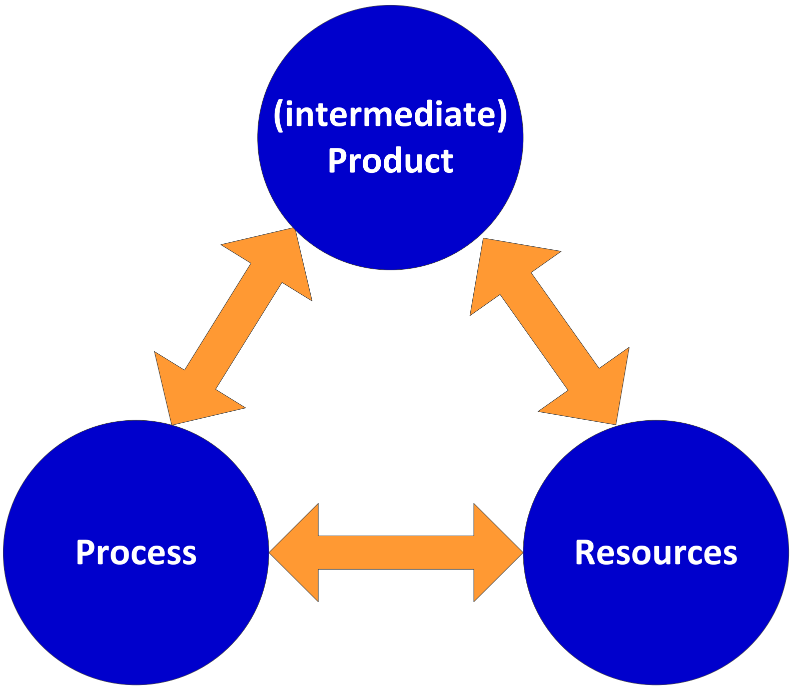

Figure 7. Product, process and resource mutual dependency

However when a process is changed, the resources and (intermediate) product might have changed automatically, since they are dependent on each other. This is represented in figure 7.

When an optimum is to be found, something has to be set constant or else everything remains variable.

Constant:

- Engineering data per ship is set constant, as mentioned in chapter 1.

Most casco intermediate products and therefore processes are determined during engineering. Ship systems, which determine the number of outfit components, are set constant. Outfit components can be installed in several intermediate casco products, or phases of production. These are currently not determined by engineering but by the local work preparation. Information regarding outfit can be found in chapter 3, and about their phases of installment in chapter 5.

- Annual man-hours (a resource) is set constant, as mentioned in chapter 1.

Variable:

- Interim products or building strategy:

As mentioned above, the outfit components can be installed in several intermediate casco products, or phases of the production process. This is called building strategy. Changing the building strategy means changing of some intermediate products, which is currently done by local work preparation.

- Other resources than man-hours:

As mentioned before in this chapter, the other shipyard's resources than labour, are production area, transport and production machines

2.1.2 Work and product breakdown

Ships are generally too big and complex to be assembled one go. In several stages of the shipbuilding process, different intermediate products are assembled. In order to map the entire shipbuilding process, first the product that is to be built is analyzed. The ship (final deliverable) is composed of smaller buildable parts, or intermediate products. The parts hierarchy is structured for building methods (manufacturing processes). Not for ship systems, since this research view is not a ship design or operation related, but manufacturing related.

The product model can be called the Work Breakdown Structure (WBS). During the shipbuilding process the WBS is assembled during different sub-processes.

In the manufacturing industry this structure is often called the Product Breakdown Structure (PBS) or Bill of Material (BoM). However, a PBS is a tree structure comprising of parts and intermediate products that are always assembled in this way. In this research, as explained in 2.1.1, the way of assembly can vary: the advancement of certain interim products can be changed..

In literature the WBS is used in project management [16]. The use of names is not entirely correct, since this research is process, and not project oriented. The main difference is that a project has a start and a finish (finite), while a process is considered to be continuous. But since both names are incorrect, for the previously mentioned reasons the term WBS is used.

2.1.3 Process resources

The main goal of this research is to create an investment plan to attain an optimal yard layout for Damex. Investments are made in new resources. Generally, the resources used in shipbuilding are [3, 4]:

Area: Area can be divided in production area and buffer area. Production processes require an area. A process requires input materials and output products, which also require an area. This means that buffers are required. Area can be outside or under a roof.

Transport machines and facilities: Transport can be done in two ways: transport of parts between sub-process buffers and making a motion (repositioning) during a process. Transport has nothing to do with processing or assembly. Transport machines and facilities at a shipyard can comprise of cranes, forklifts or section transporters.

Production machines and facilities: Production machines are machines that are required for processing or assembly of (intermediate) products. Production machines and facilities can comprise of cranes and steel part processing machines.

Workers: Workers are required for processing or assembly of (intermediate) products. Workers can be required to operate production machines, or can perform manual labour, sometimes aided by machines and facilities.

Considering shipbuilding, the previously stated resources are re-usable.

2.1.4 Used process analysis method

By using the original PROPER method, research scope and the stated shipyard products and resources, a process analysis method is derived. The process analysis method is represented in figure 8.

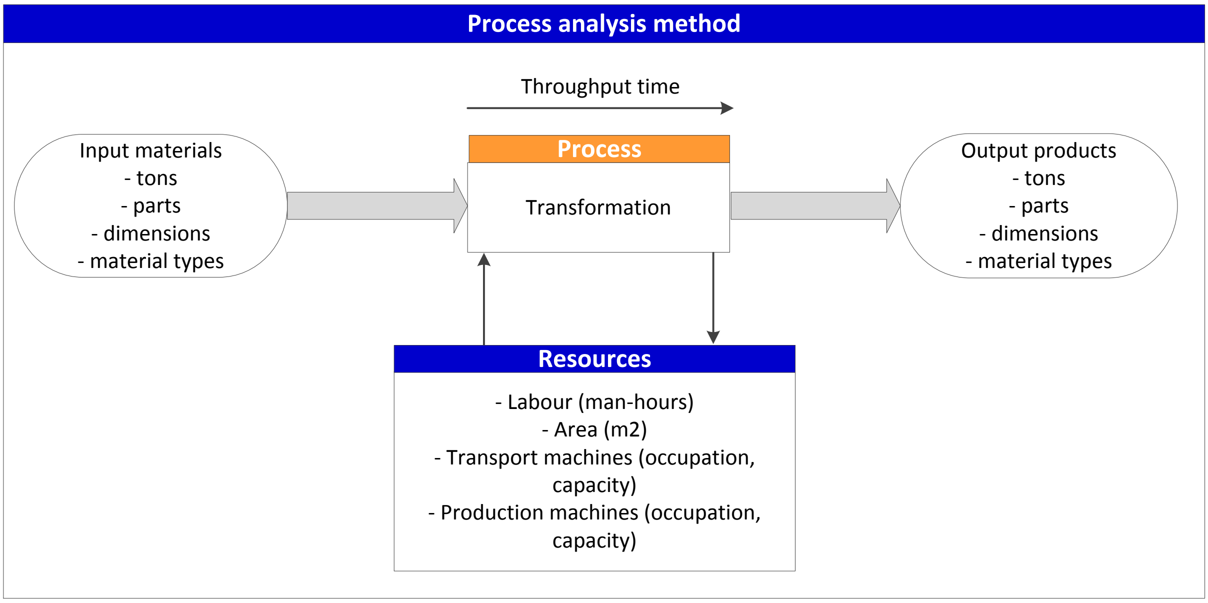

Figure 8. Used process analysis method in this research

By using this tool, the shipbuilding process can be represented as a series of transformation processes.

2.2 Methods of improving the productivity of a shipyard

When the shipyard is sufficiently modeled according to the PROPER method and scope of this research, methods for improving the productivity of a shipyard are looked at. These methods are determined by using methods found in literature and by looking at other more productive shipyards. In this section the four productivity improving method types are described.

2.2.1 Increased mechanization

The first method is to increase the mechanization of the shipyard. When specialized machines are used, processes can be performed faster or less workers are required for the specific process than before. Disadvantages are that machines can be expensive and require maintenance. Also specialized machines can only perform one specific process. This means that flexibility can be reduced. A high degree of mechanization is a trend in Western European, North American and East Asian shipyards [3, 4, 5].

2.2.2 Increase learning effect by more repetitive work

Experience breeds competence. When workers are highly specialized by doing something very often, they usually become very good at it and very fast. This is called the learning effect. The learning effect is most effective when large numbers of the same product are produced (series manufacturing) [2, 3, 9, 10, 11]. In the shipbuilding industry numbers are generally low. However, intermediate products can be produced in greater numbers.

2.2.3 Increase advancement of interim products

In this case advancement of interim products means installing more outfit in smaller/earlier intermediate products. Generally called pre-outfitting, following this method outfit parts can be installed in less awkward positions than when these parts are installed during later phases/in bigger intermediate products [3, 4, 5, 21, 24]. Installing components in less awkward positions saves time, because work is much easier.

2.2.4 Reduce non value adding time or 'waste':

This method does not aim at making the assembly more effective or faster, or changing the intermediate product, but to reduce time that is not used for assembling the actual product [2, 3, 25, 26, 30].

2.3 Methods of ensuring validity of research

During modeling the ship production process into a system and implementing improvements in the system, validity must be ensured. A good way to ensure validity is by using 3 different sources or methods that result in the same conclusion. In this section is explained how this is done.

2.3.1 Validity of process model (conceptual model)

During the creation of the PROPER shipbuilding process model, it is vital to ensure validity. Validity of the conceptual model is ensured when "*the theories and assumptions underlying the conceptual model are correct and the model's representation of the problem entity and the model's structure, logic, and mathematical and causal relationships are "reasonable" for the intended purpose of the model*" [7].

Validity is checked by using 3 different sources (sometimes called triangular validity) in this research is done by own observations at Damex and other shipyards; by using literature and other previous research; and by checking findings with experts.

2.3.2 Validity of data

Ensuring data validity is more difficult. Bad or insufficient data is often the cause of a failed validation of a model [7]. In this research the aim is to ensure validity by using global (overall shipyard or per ship) historical data; local (department or per interim product) data and checking findings with experts. When there is too little historical data, both global and local, data can be measured if possible or engineered by using specific machine data [4]. Data can also be derived from expert experience numbers. Best is to back these number up with other sources.

These has to be sufficient data to build a conceptual model and validate it [7].

3 DAMEX PRODUCT MIX ANALYSIS

A production plant is dependent on the products that are to be built. This is why the products are the first research objects in this research. A ship is a complex product, consisting of a rigid steel construction, navigation systems, operation systems, HVAC installations and living quarters. These systems form the ship and are designed in such a way that they perform their tasks in an optimal way. However for production operating systems do not really matter. For example a fuel pipe spool is installed in roughly the same way as a ballast pipe spool. Therefore the products are analyzed with manufacturing focus. The secondary research question that is answered in this chapter is:

- **What (intermediate) products, or workloads, are to be built at Damex?**

The chapter starts with a description of the product mix. The three product's functions and characteristics are described. After that the used WBS is described. The data of each WBS part is given. After that the product scenarios are described and finally the validity methods and data is checked.

3.1 Mix of different ships

A production plant is dependent on the products that are to be built. Damex builds several ship types. A mix is chosen to represent each ship types built at Damex.

Damex is a shipyard that can manufacture both steel and aluminium ships. This makes the product range quite variable. Its past order portfolio consist mainly of Stan Tugs, some fishing vessels and a couple of fast ferries. Currently and in the near future several Stan Lander ships, Stan Tugs and some Stan Patrol ships will be manufactured.

The following ships are assessed:

3.1.1 Stan Tug 2208

Figure 9. Stan Tug 2208 (DSGo database)

The STu2208 is a heavily constructed and curved ship. The ship is a harbour tug, and the main function of a tug is to tow other ships. This means that the ship's systems are designed purely for towing power. This means that big engines and a lot of cooling systems are required, and for example less accomodation and storages.

Heavily constructed ship, sufficient outfit space. Less detailed planning of this ship is available. There is registered reference data of two produced ships. Data about several comparable, but smaller and larger, ships is also available. Less downtime was experienced during the construction of these ships, which means less waiting. This ship type has 75mh/ton steel of Dutch reference productivity.

3.1.2 Stan Lander 5612

Figure 10. Stan Lander 5612 (DSGo database)

The SLa5612 is a heavily constructed and mostly straight ship. The ship's function is to perform ferry duties in the coastal area with bad infrastructure (no ferry terminals). This means that a lot of deck space for cars/trucks, a robust underwater construction and significant ballasting capacity are required. Some accommodation is required for a small crew. Speed is not much of an issue, so the engines are relatively small.

Ship is heavily constructed, sufficient outfit space. A detailed local production planning is available, containing experience numbers of Damex management. Registered reference ship man-hours are available. However, it is about the first of series of 4. This ship was one of the reasons for this project, since there were too many registered man-hours. The reasons for this include much rework; ship assembly measurements problems because of lacking section building measurement control; much waiting hours since some of the, already inadequate number of, cranes are broken, or by power failings. The total steel reference productivity of the 'ideal' Dutch shipyard is. 65mh/ton steel.

3.1.3 Stan Patrol 4207

Figure 11. Stan Patrol 4207 (DSGo database)

The SPa4207 is a lightly constructed and curved ship. The main function of the ship is to patrol the coastal region for smugglers. In order to patrol effectively, speed and endurance are required. This means that the ship is to be light, heavily powered, and have significant accommodation and storage space.

Ship is lightly constructed and has narrow outfit space. Limited amount of data. No reference ships have been built at Damex. Only the Dutch reference hours of 140 mh/ton steel and local planning estimates are available as production checks. In accordance with the other ships the man-hours are estimated.

3.2 Product and work breakdown

To build a complex product, it is feasible to break it down to workable pieces. In project management this is called the Work Breakdown Structure (WBS). A hierarchically decomposed product is called the product breakdown structure (PBS). The product structure is a level above the Bill of Materials (BoM). All interim products used in the PBS are deliverables in itself that are either produced at the shipyard or purchased/subcontracted. However, since the PBS tree is not entirely certain yet (as explained in chapter 2), the WBS is used in this research.

The ship (final deliverable) consists of a steel (or aluminum) casco and its outfit. Usually ship designers and engineers divide the ship into systems. In this research the product structuring view is manufacturing, which means the casco deliverables are primarily divided for building method and the outfit deliverables are divided for outfit method.

3.2.1 Casco

The casco is the steel (or aluminum) structural cohesion of the ship.

The casco is broken down below, descending from size:

- Block: several sections can be assembled to form a block.
- Section: A section is a 3D assembled part of a ship. A section is assembled from 2D parts. These can be (rigid) main-, or sub panels and steel parts.
- Rigid main panels: Sub panels mounted on a main panel. This process is the primal reason for the division between main- and sub panels. A rigid main panel is still a 2D part.
- Main panels: Assembled plate fields of multiple plates with profiles attached.
- Sub panels: Plates with profiles attached.
- Steel parts: Smallest steel part at this level. Consist of plates, profiles and small parts

Plates and profiles can be straight or curved.

3.2.2 Outfit

Outfit has been split by building constraints:

- Hot outfitting: Outfit materials that have to be welded to the casco. Sometimes flame cutting is required to fit the outfit. Hot outfitting can only be done on unpainted steel.
- Cold outfitting: Outfit materials that can be mounted to the casco other than welding. To prevent corrosion, cold outfit materials can only be fitted on sufficiently painted steel
- Painting can only be done when all other workers are away because of health and material reasons. Painting is required when all hot structural works and outfitting is done for the specific surface.

Hot outfit consists of:

- Steel outfit parts: foundations, little tanks, cable trays, insulation pins, man-holes, steel doors, steel window frames, stairs, handrails, boulders, other small steel
- Piping: penetrations, pipe clamps, spools, fitted pipes, other fittings
- HVAC ducts: pre-fabricated ducts, duct clamps, penetrations, sheet metal

Cold outfit consists of:

- Insulation: Accommodation wall, floor and ceiling insulation; HVAC system insulation, pipe system insulation; engine room insulation
- Cables: electric grid cables, small switchboards, cable harnesses
- Joinery: floors, wall panels, ceiling panels, furniture
- Pipe spools: pre-fabricated spools (painted, to be mounted by bolts)
- Big equipment: engines, generator sets, switchboards, propellers, rudders, big pumps etc.
- Other materials and equipment: small pumps, valves, lights, coffee machines etc.

Painting consists of:

- <u>The conservation system</u>: The conservation system has to dry after it has been applied, which means that other activities cannot take place during this time.
- <u>Cast/screed floor:</u> The same problem as with conservation systems applies when applying a cast/screed floor.

3.2.3 Product model

The manufacturing structured work breakdown is shown below.

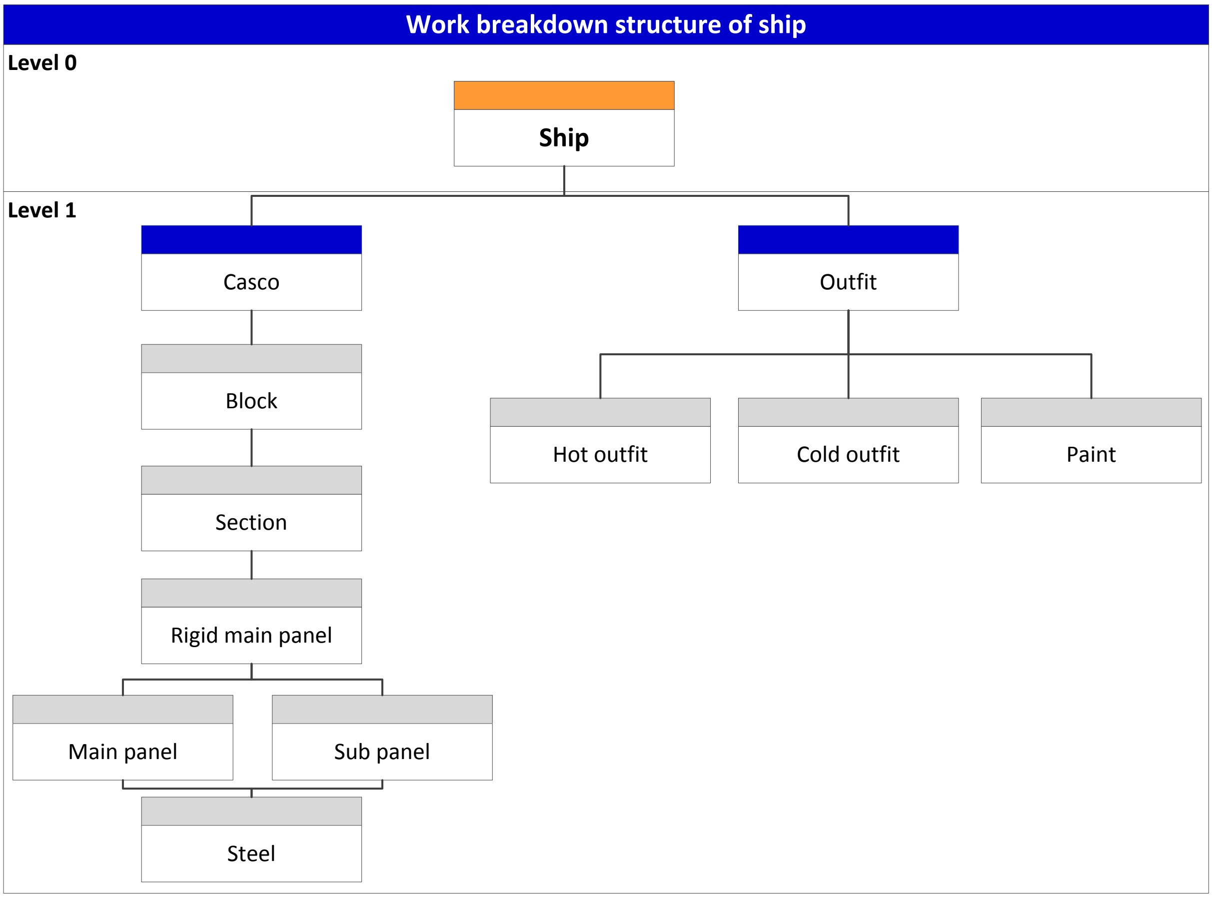

Figure 12. Work breakdown structure

3.3 Product mix data

The products and the product model are established. The next step is to determine the quantity of the product model parts of each product in the mix.

The data is already sorted for calculation. The reasons why these data is selected is shown in chapter 5.

3.3.1 Stanlander 5612

For the SLa5612 the most data is available. Detailed casco statistics are made available thanks to Jos Kooij's graduation project.

Table 1. SLa5612 casco parts

	Steel parts	Main panels	Sub panels	Rigid main panels	Sections	Blocks
Number (#)	7102	74	382	33	29	8
Total weight (tons)	443	n/a	n/a	n/a	443	443
Average weight/part (tons)	n/a	n/a	n/a	n/a	14,5	54,5
Max weigh/part (tons)	5	15,9	1,1	19	49	65
Average area/part (m2)	n/a	31,8	2,7	31,8	80,8	80,8
Max area/part (m2)	n/a	113	14	113	113	113
Area standard deviation (m2)	n/a	49	4,5	49	12	12

Regarding outfit the specific weights per sent part from DSGo are available. However, outfit produced locally, the number of parts or weight is not known at DSGo. Some information was still present at Damex, but not all.

For example, the weight distribution of the spools is unknown. The total weight of all pipe pieces is known. The average weight per spool is about 70 kg, which is more than 50 kg. Therefore all spools are considered to be mounted by using a crane. The same is for the foundations for big equipment. At the carpentry shop furniture is made, and again there is no information available. All furniture assemblies are assumed to be less than 50 kg. While for example the oven or laundry machine can be more than that.

As shown above, these data is not necessarily accurate, but more information is required to give a more accurate figure.

Table 2. SLa5612 outfit parts

	Hot outfit parts: no crane	Hot outfit parts: crane req.	Cold outfit parts: no crane	Cold outfit parts: crane req.
Number (#)	1037	850	3726	53
Max weight/part (tons)	50 kg	2 tons	50 kg	4 tons

To determine all steel part processing machines, more detailed information regarding plates and profiles is required. These data is available thanks to Jos Kooij's graduation project.

Table 3. SLa5612 steel part processing parts

	Cut and marked (tons)	Formed (tons)	Flanged (parts)	Beveled (meters)	Grinded (parts)	Sorted (parts)
Plates	329,5	48,6	312	202	4500	860
Profiles	98,5	20,7	n/a	n/a	2250	500

3.3.2 Stan Tug 2208

For the Stu2208 much data is available. Detailed casco statistics are made available thanks to Jos Kooij's graduation project.

Table 4. STu2208 casco parts

	Steel parts	Main panels	Sub panels	Rigid main panels	Sections	Blocks
Number (#)	2854	24	291	10	9	3
Total weight (tons)	97,5	n/a	n/a	n/a	97,5	97,5
Average weight/part (tons)	n/a	n/a	n/a	n/a	10,7	33
Max weigh/part (tons)	5	5,6	0,7	8,2	35	45
Average area/part (m2)	n/a	20,1	1,5	36,6	36,6	46,6
Max area/part (m2)	n/a	72	13	72	72	88
Area standard deviation (m2)	n/a	11,5	1,5	7,4	7,4	20

Regarding the outfit of the STu2208, no weights are available at DSGo. Therefore the weight distribution and the average weight of spools or foundations are unknown. Therefore the assumption is made that they are more than 50 kg, which again is not necessarily true, but more information is required to give more accurate figure.

Table 5. STu2208 outfit parts

	Hot outfit parts: no crane	Hot outfit parts: crane req.	Cold outfit parts: no crane	Cold outfit parts: crane req
Number (#)	212	557	1026	62
Max weight/part (tons)	50 kg	2 tons	50 kg	7 tons

To determine all steel part processing machines, more detailed information regarding plates and profiles is required. These data is available thanks to Jos Kooij's graduation project.

Table 6. STu2208 steel part processing parts

	Cut and marked (tons)	Formed (tons)	Flanged (parts)	Beveled (meters)	Grinded (parts)	Sorted (parts)
Plates	82,3	46,4	200	87	1200	320
Profiles	15,2	7,1	n/a	n/a	1000	200

3.3.3 Stan Patrol 4207

For the SPa4207 the data is not complete (no construction plan, systems incomplete, shell plates missing in 3D model etc.). By comparing the available data to the existing ships, the data is guesstimated. The results that are calculated by these data are of course not very reliable.

The SPa4207 is, like all High Speed Craft, lightly built. This means that the plates and profiles are thin. The superstructure is constructed from aluminum. The average plate thickness is 6mm compared to the 11mm of the other ships.

The specific weight of steel is 2,8 times that of aluminum. In this research aluminum weight is calculated in steel work equivalent tons. This is used for the productivity numbers that use tons as an estimator.

Table 7. SPa4207 casco parts

	Steel parts	Main panels	Sub panels	Rigid main panels	Sections	Blocks
Number (#)	5800	40	300	18	8	4
Total weight (tons)	112,3	n/a	n/a	n/a	112,3	112,3
Average weight/part (tons)	n/a	n/a	n/a	n/a	9,8	20
Max weigh/part	3	5	1	7	22	30

(tons)						
Average area/part (m2)	n/a	21	1,5	21	56	100
Max area/part (m2)	n/a	84	6	84	84	119
Area standard deviation (m2)	n/a	14	0,75	14	28	10

Concerning outfit there is no data about spools, small steel assemblies or carpentry assemblies. The current data of this ship is incomplete. By comparing the available data to the existing ships, the data is guesstimated. The results that are calculated by these data are of course not very reliable.

Table 8. SPa4207 outfit parts

	Hot outfit parts: no crane	Hot outfit parts: crane req.	Cold outfit parts: no crane	Cold outfit parts: crane req
Number (#)	634	638	3236	75
Max weight/part (tons)	50 kg	2 tons	50 kg	8 tons

To determine all steel part processing machines, more detailed information regarding plates and profiles is required.

Table 9. SPa4207 steel part processing parts

	Cut and marked (tons)	Formed (tons)	Flanged (parts)	Beveled (meters)	Grinded (parts)	Sorted (parts)
Plates	100,3	60	100	100	4000	600
Profiles	12	8	n/a	n/a	1000	300

3.4 Product scenarios

The product scenario number of variables is kept as low as possible. The extremes of the product scenarios are the production of only one ship type. This is done for all three ships.

The number of direct ship assembly employees is initially set constant to 100 (the current amount fluctuates around this number). This results in 5,1 STu2208, 2,05 SLa5612 and 2,9 SPa4207 ships per year. In order to keep things simple, the initial amount of ships in each scenario is set to be 5 STu2208, 2 SLa5612 and 3 SPa4207 ships per year. To keep things comparable, the results can only be compared per each scenario. The percentages however can be compared to each other.

3.5 Validity of product model and data

The quality of a computerized model is as reliable as its data. Therefore, when the model itself is valid, the input data must be as valid as possible.

3.5.1 Product model validity

The product model, or WBS, is primarily based on the current engineering product model. Some parts have been simplified and some have been extended, following the work of J. Kooij. All parts in the WBS were observed during my stay at Damex and at other shipyards. The WBS has been confirmed by experts [J.B.B Teuben; R. Kentie].

3.5.2 Data origins

The product portfolio of Damex consists of 3 ship types (Stu 2208; SLa 5612; SPa4207). These products are divided following the WBS.

Ship data is gathered from 3D NUPAS models of DSGo, including the parts lists of steel plates and profiles, which form sections, blocks and finally the ship. However, data of sub, main and rigid main panels is not known at DSGo since it is considered local work preparation. Jos Kooij has distilled the panel data from the existing DSGo data which is used in this research.

Outfit data is gathered from various sources: from the 3D Cadmatic model, jobbooks (material list) and IDK reports.

3.5.3 Data reliability per ship

Data of SLa5612 is the most complete. This ship has a complete 3D model, including outfit part lists. Pipe spool data is gathered from Damex pipe shop.

Data of Stu 2208, casco data is good and pretty complete. Outfit data is very limited. The number of spools is estimated as described in chapter 3.

Data of SPa4207 is very limited. Construction plan is missing. Outfit data is available, but not complete. Number of spools is estimated as described in chapter 3.

3.5.4 Data quality

The gathered ship data of the SPa4207 is not of good quality. I have been unable to visit Damex for a second time to gather detailed product information from work preparation and experts, since hurricane Sandy paid a visit. See Appendix J for more information about hurricane Sandy.

4 DAMEX OVERALL SHIPBUILDING ANALYSIS

In chapter 3 the (intermediate) products that are built at Damex are analyzed. For determining an optimal yard layout for Damex, it is important to know how and where these (intermediate) products are currently built. In this chapter the overall shipbuilding process at Damex is analyzed. The method of analyzing a process is stated in chapter 2. The PROPER model, adjusted for the research scope, is applied for the first time in this chapter for analyzing the overall shipbuilding process. In this chapter the following secondary research question is (partly) answered:

- **How can a shipyard production process be modeled into a system?**

First the overall shipbuilding process is described and modeled in accordance to the PROPER model. After that the four main distinguishable shipbuilding processes are analyzed.

Damex is a shipyard located on Cuba. Cuba has some essential political, logistical and technological characteristics to consider. Therefore the Cuban shipbuilding circumstances are described in this chapter. Some of the four main distinguishable shipbuilding processes are not necessarily the core business of Damex. Therefore the process analysis scope is further tightened.

4.1 Overall shipbuilding process

In order to build this complex product, several processes have to take place on the shipyard. A manufacturing process requires: material, information and resources [1]. Information flow is not looked at for this research and material is modeled by the previously mentioned WBS and product mix. This material (product mix) is handled by the resources of the shipyard. Therefore resources are directly dependent on the WBS and product mix.

The quantity and quality of these resources have to be determined. To do this, the shipbuilding process is analyzed and modeled in accordance to the PROPER model. In this model the required resources are indicated. The simplest shipbuilding process model is the following.

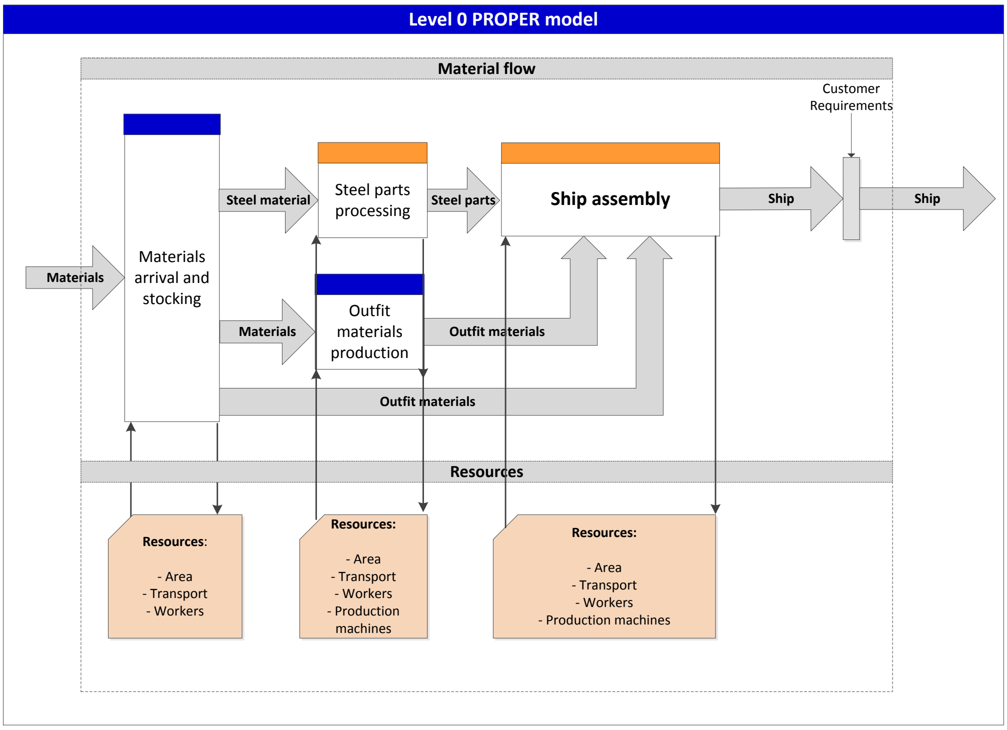

Figure 13. Level 0 shipbuilding process PROPER model

4.1.1 Materials arrival and stocking

The first thing that happens when building a ship is that materials come in and are stored. There are many kinds of materials. First a division is made whether it can be stored outside or not. When it can, it is stored at the material park outside. If not, the value, size or time determine whether the materials are stored in the warehouse inside a building or in containers.

When materials are required, the order is picked and transported to the concerning department.

4.1.2 Outfit materials production

Outfit materials can be pre-produced. Installing pre-produced outfit material takes less time than producing the material on the spot. Pre-producing can be done on board or in specialized workshops. When outfit materials are pre-produced in specialized workshops it is done more efficiently, since production takes place under a roof, tooling can be optimized and material supply can be closer than on board. It depends on the type of material and product type what tools are required.

4.1.3 Steel parts processing

Ships cannot be made from straight steel plates and profiles of one size. They have to cut and formed to size first. These parts also have to be registered, since it is easy to know which part of the ship is which when assembling the ship. Raw steel parts are processed to customized steel parts for assembly by using different metal processing machines.

4.1.4 Ship assembly

A ship can be assembled by using all the above stated materials. First (parts of) the casco are assembled, and after that outfit can be installed. When the ship is erected and launched it can be finished.

4.1.5 Overall resources

In order to complete these processes, resources are required. Generally speaking these are: <u>area</u>; <u>transport machines</u>; <u>workers</u> and <u>production machines</u>.

In 2011 the total number of employees was 170, and grew to 180 at the end of 2012. The number of direct ship assembly workers varied from 95 to 105. On average this is 100, which is taken as constant in this research. The rest of the employees are working for management, office, maintenance, transport, warehouse, outfit materials production and ship repair.

Table 10. Damex gross data

Material stocking	**Department**	m2	lifting capacity (ton)		
	Stocking materials and containers outdoor	8000	5		
	Stocking materials indoor	700	1		
Vessel prefabrication	**Department**	m2	lifting capacity (ton)	steel capacity (ton/year)	
	Plate and profile cutting	750	1	>700	
	Panel and section building	3500	100	6-700	
Vessel assembly and outfitting	**Department**	l (m)	b (m)	lifting capacity (ton)	max weight ship (ton)
	Slipway 1 (covered)	60	16	40	600
	Slipway 2 (outdoor)	100		100	>600
	Slipway 3 (repair, outdoor)	40		100	200
Outfitting quay	**Department**	max length (m)	lifting capacity (ton)		
	Outfitting at quay	100	10		
Outfit materials production	**Department**	m2	lifting capacity (ton)		
	Pipeshop	500	1		
	Small steel shop	500	1		
	Mechanical workshop	250	1		
	Carpentry workshop	250	1		
	Electric workshop	200			

4.2 Materials arrival and stocking

Every material that is installed in a ship at the shipyard has to arrive and be stored for production. The materials that are to be stored are described in the WBS.

More storage means more space and risk of accidents or theft. Less storage means more dependability on regular supply. Time in storage means higher financing costs, since materials and equipment have been paid for in advance of ship delivery, whether by customer or shipyard. In Cuba supply is not dependable, and therefore a substantial stock has to be maintained, usually the entire ship. This is why the Damen Technical Cooperation (DTC) product group is managing the projects and material coordination for Damex.

The arrival and stocking process is generally as following: material arrives, is registered and stored. When a call from production arrives, the production batch is picked and sent to production.

A division can be made by material that can be stored outside and inside. Observations show that steel material like plates, profiles and pipes can be stored outside. Everything else is stored inside, whether in the warehouse or inside containers.

The process of warehousing is very important for a shipyard, but is not the main value adding process. Improvements can be done regarding the use of space and forklifts at the shipyard.

4.2.1 Inside storage

Figure 14. Damex warehouse and container storage

Fragile equipment, like switchboards or generators, is stored in the warehouse for protection against weather, accidents and theft. Other materials can be stored inside containers. Damex management requires more inside storage space. This is currently being worked at by extending the existing warehouse. No investments are required here.

4.2.2 Outside storage

Observations show that steel plates, profiles and pipes are stored outside in the material park. The handling of these materials is done by big forklifts. These resources require a lot of maneuvering space. Observations at other shipyards show a more compact storage by using an outside gantry, or overhead crane for steel materials.

Transport of these plates, profiles and pipes to other places at the shipyard can still be done by a forklift, but by using a cart to hold the steel. This way the net steel storage remains the same, but a lot less space is used for transport. Another, better method is to have the materials very close to production. The gantry crane can pick up the steel part and put it on a roller track. This way the forklift and cart are no longer necessary.


Figure 15. Damex profile, pipe and sorted parts storage; and plate storage

When new facilities are to be built, the area for outside material storage must be reduced. In this research improving the area use of the material park requires investing in a gantry crane (10t) along with a crane track of 50m. There is no data about additional cash flow. More research is required for this.

4.3 Outfit materials production

Some outfit materials come in ready for outfitting and are stored inside containers or in the warehouse. Some need some processing. Production of outfit materials at Damex is done in specialized workshops. In this paragraph a description is given of what is done in the existing outfit material production workshops and what not.

4.3.1 In-house or outsourced outfit material production

Outfit materials production can be done by the shipyard itself, or it can be outsourced. Generally speaking, in the Netherlands shipyards the outfit materials production is mostly outsourced to specialized companies. But at Damex it is impossible to outsource anything to Cuban companies because there are none. Processed materials can be imported from the Netherlands, but these products are usually more expensive than when they are produced at Damex itself. Therefore the outfit material production that is currently operational at Damex is considered to stay there.

Improvements can be done, since the production capacity is to be increased. In this research the advice of the current foremen is used whether they need new machines. It is not clear if and how much extra cash flow these improvements will generate. More research is needed to determine this.

4.3.2 Small steel constructions prefabrication

In this shop the small steel parts are fabricated. Small steel is a collection name for all non-structural steel parts on a ship. These parts vary from little tanks to foundations of outfit to railings and stairs. Production takes place on work benches. The tooling consists of flame cutting torches, welding machines and small specialized tools like a small plate roller, a railing bending tool and a defective guillotine plate shear.

According to the small steel foreman there is a need for a bigger transport crane, a small plate flanging machine and a working guillotine plate shear.

Historical data show that 50% of the small steel man-hours are performed in the small steel workshop.

4.3.3 Pipe spool prefabrication

Pipe spools are fabricated here. Pipe spools are prefabricated pipe pieces, ready to mount on board. Spools consist of pipe pieces (straight or curved), flanges and other fittings. Curved pipe pieces are bent when possible, but when the diameter is too big, need to be cut and welded several times. The current production capacity is barely sufficient.

When more production is required the pipe shop foreman needs a semi-automatic mandrel pipe bending machine with bigger pipe radius capacity than the current one. For producing Sla5612 pipe spools their machine is too small, which results in significantly more man-hours, since the spool has to be brought in shape by cutting and welding instead of bending. How much more man-hours this is exactly is not clear.

Historical data show that 33% of the total pipe fitter man-hours are performed in the pipe workshop. For the Sla5612 this is more (50%), since the pipe bending machine is too small.

4.3.4 Carpentry prefabrication

Furniture and wall/ceiling panels are prefabricated in this shop. Machines like saw benches, a sanding machine and several work benches are located here. According to the carpentry foreman a new sawing machine and more space is needed when production is increased. The extra space is currently being built, so this isn't a problem. The saw machine costs €15 000,- [32].

Historical data show that 33% of the carpentry man-hours are performed in the local carpentry workshop.

4.3.5 Electrical workshop

Cables are measured and cut in this shop. The shop is big enough. Better engineering information is required. Currently, first the cable length has to be measured in the ship before it is cut, while this information is accessible in the 3D model at DSGo. Information flow is however not in the scope of this research. Cable trays are imported from the Netherlands. There is no indication that this will change.

4.3.6 Steel outfit parts machining

Round steel outfit material, like boulders and shafts can be fabricated in this shop. There are several old machines like lathes, milling and drilling machines etc. Currently only parts for repair jobs are fabricated here and there is no intention to change this. Engines and shafts require quality machines, with regular quality checks, which is not feasible for this workshop in Cuba (R. Kentie).

4.3.7 Other outfit materials

HVAC workshop: There is no HVAC workshop at Damex. Insulated HVAC ducts are imported from the Netherlands. There is no indication this will change.

Insulation workshop: No insulation workshop at Damex. Insulated HVAC ducts are imported. Pipe and wall insulation are prepared on board. This can be improved, but not in scope of research.

Paint workshop: There is currently no paint workshop at Damex. Painters work on location with paint rollers. Paint is stored at an old paint storage. Foundations, cable trays and pipes are painted on board. A new small steel paint shop with paint blasting capacity is required by Damex management.

As stated before, the outfit materials production processes are required at Damex and some improvements can be made. No further analysis is necessary for these processes.

4.4 Steel parts processing

Ship production starts with steel parts processing. In the following paragraph the steel part processes are described. Steel can be separated between plates and profiles. During the steel part processing these plates and profiles can be cut, marked, bent, flanged, beveled and grinded.

4.4.1 In-house or outsourced steel parts processing

At Damex this is currently not possible to do all steel part processing in-house, since there is no plate forming press and the plate cutting machine is not reliable. So curved plates are always outsourced in the Netherlands, and a lot of plate cutting also.

Regarding steel part processing, there is the possibility to follow the current approach (use current machines, outsource most work in the Netherlands), or to invest in new machines in order to do everything in-house. Steel part processing locally is considered much cheaper than outsourcing in the Netherlands; outsourcing costs double. For example, an outsourced steel package of the Spa4207 costs €100 000,- and €50 000,- in-house [J. Kossen].

Man-hours will not be reduced in this way. But it is useful to see if the investment is feasible. Therefore the number of required machines is calculated in this section.

4.4.2 Plate processing

Plate processing means the preparation of delivered standard sized straight plates to plate material fit for ship production. Several of these preparations are needed for all plates to be ready for production. Some plates require more processing:

- Cutting the plate to size (all plates)
- Marking (line and text) the plate with production information (all plates)
- Beveling the plate edges for welding requirements (plates to be butt welded)
- Folding/flanging the plate (some plates)
- Forming/curving the plate to the right shape (some shell plates)
- Finishing/grinding the plate for safer handling (plates with sharp to be painted edges)
- Sorting for production (all plates)

In this paragraph

Cutting and marking

At Damex (and most other shipyards) the cutting and marking of plates is done by a CNC cutting and marking machine. This machine is shown in figure 16. Line marking is done by the machine and text marking is done by hand.

Figure 16. Damex plate cutting and marking and plate beveling

A rough division between nesting plates and production plates can be made. A lot of small plate parts that are to be cut from one nesting plate, which means a lot of cutting meters and less line mark meters. Production plates are plates that have to be cut to the right production size, and have less cut meters, but more line mark meters. Text marking is currently done by hand.

The current machine is composed from several old cutting machines, and is very unreliable. In order to reduce delays by machine failure a new machine would be nice (J. Kossen, DTC). Currently cutting is sometimes outsourced in the Netherlands to ensure reliability.

This process requires transport (crane and forklift at Damex); workers (machine operators, transporters); a production machine (CNC cutting and marking) and an area (inside building, machine + machine work buffer).

This machine has two cutting beds of 6*3 meters, or one of 12*3 meters. When using two beds, and when sufficient transport resources are available, the plate cutting and marking machine can produce 3000 tons of steel plates. A bigger machine with two cutting beds of 12*3 meters can roughly produce 5000 tons.

Given the current theoretical production capacity a bigger cutting and marking machine is not necessary, since a 200% increase leads to a production requirement of a maximum of 2000 tons. But since the current machine is very unreliable a new one is considered for doing steel part processing in house.

Plate beveling

When welding requires plate edges to be beveled, this can be done by a beveling machine (hot process). Plates are beveled when they are to be butt welded. Particularly a submerged arc butt weld requires a bevel to let the heat go deep enough. Plate edge beveling is done partly during the plate processing, and partly during block- and ship assembly. The beveling machine is guided along the edges.

The required resources are an area (inside building or outside, machine + machine work buffer); transport (crane/forklift at Damex); workers (machine operators, transporters); and a table with the bevel tractor.

Beveling is done on a plate edge. Therefore it is calculated per meter of plate edge. One worker with a beveling tractor can bevel 40 000 meters of plate edge per year. 40 000 meters is more than enough for Damex, since a 200% production increase will result in only 1500 bevel meters max.

Plate folding

Plate folding or flanging is done when plates have to be formed in an acute angle. This is done in a folding or flanging machine. At Damex there is a folding/flanging machine present. It has been used for forming, but the curve quality was surprisingly disappointing.

Figure 17. Damex plate folding and Bergej shipyard plate forming

The required resources are an area (inside building, machine + machine work buffer); transport (crane/forklift at Damex); workers (machine operators, transporters); and the folding machine.

10000 plates can be folded per year by one folding machine. Another machine is not required. When production is increased by 200%, the total folded plates will not exceed 2000.

Plate forming

When curved plates are required, a plate forming or curving machine is required. Curved plates are used for the shell of the ship. Plates can be 2D formed by a roller press or 2D forming press, or 2- and 3D formed by 3D two shafted forming press. Two cranes are required to manipulate the plate when pressing.

Damex has no plate forming capacity, except for the folding machine, so curved plates are currently outsourced in the Netherlands. Plate presses were observed at Bergej Shipyard, IHC Metallix and at DSNS. The capacity of one plate press was more than enough for Bergej Shipyard and DSNS, which both have a bigger steel throughput capacity than Damex. IHC Metallix had two and has a significantly higher steel throughput capacity than Damex.

The required resources are an area (inside building, machine + machine work buffer); transport (crane/forklift at Damex); workers (machine operators, transporters); two production cranes and the forming machine.

Concerning the current standard plate type (6*2,5 meters), 600 tons of steel can be formed per year by one forming press (under the current assumptions). When production capacity is increased 50% this is not a problem. When production is increased by 200% this might be a problem when building only tugs, since under those conditions 700 tons of formed steel is required per year. But more and better data is required to give a better prediction.

Plate grinding

When plates are cut, sometimes the sharp edges have to be grinded. This is to ensure paint adherence. Moreover it reduces the chance of injury and the handling speed of the part. This means that only edges are to be grinded that have to be painted. Generally these are the small brackets and holes in plates.

The required resources are an area (inside building or outside + local work buffer); workers (grinders, transporters); transport (crane or forklift)

Roughly 13000 parts can be grinded per year by one grinder. When production is increased by 200% a maximum of 45000 parts (plates and profiles) is to be grinded. This will take an average of 3,5 grinders per year. When production capacity is increased by 50% this will be only 1,75 average grinders.

Plate sorting

When plates have been prefabricated they are sorted for production. There are several ways to sort. The current way of sorting at Damex is that all parts are sorted per section and are moved to the section build location. At the section build location the workers have to look for the specific parts they need for building main panels, sub panels and eventually the section.

Figure 18. Damex steel part sorting and DSGa (DSGo database) steel part sorting

Another way of sorting is sorting per section for sub-process: per panel, per section and ship assembly.

Plates can be stacked on the floor, on a cart or on a flat rack. When plates are stored on the floor, a crane or forklift has to move the section plate for plate. When stored on a cart, the forklift can pull it to the production location in one go. Storing on a flat rack requires a transport crane, but has the same advantages of a cart, requires less space and is faster. All processes require workers (sorters, transporters).

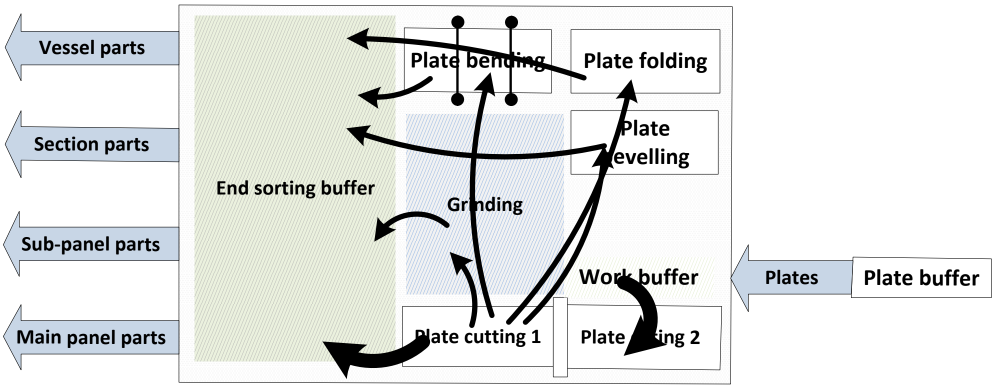

Figure 19. Steel part transports during plate processing

6600 big part or crates of small parts can be sorted per year by one sorter and crane. When production is increased by 200% a maximum of 8200 parts is to be sorted per year, which will require 1,25 sorters and cranes on average. When production is increased by 50% this will be only 0,6.

4.4.3 Profile processing

Just as plates, profiles are delivered at standard size and must be prepared for production. These preparations are:

- Cutting the profile to size (all profiles)
- Marking (line and text) the profile with production information (all profiles)
- Folding the profile (some profiles)
- Forming/curving the profile (profiles for curved shell)
- Finishing/grinding the profile (most small parts)
- Sorting for production (all profiles and small parts)

Profile cutting and marking

All profiles have to be cut and marked for production and are therefore in the main production flow. Profile cutting and marking is done by hand (hand flame cutting) at Damex next to the section building location.

An automated CNC profile cutting and marking machine is observed at DSNS in the steel specialized prefabrication hall. At Bergej Shipyard the process is done by hand as well, but in a specialized prefabrication hall. This is slightly more efficient, but the material flow over the shipyard is greatly improved and more controllable.

Figure 20. Profile cutting and marking and old Damex profile bending machine

Profile cutting and marking requires an area (inside building or outside + local work buffer); workers (profile cutters, transporters); transport (crane or forklift at Damex); production machine is optional.

One profile cutter and marker can produce 440 tons of profiles per year. When production is increased by 200% a maximum of 600 tons is to be cut and marked per year, which will require 1,4 cutters on average. When production is increased by 50% this will be only 0,7.

Profile folding

Sometimes profiles are required to be folded or flanged. When this is required, it can be done at the plate forming press with a specific punch. There is no special machine required for this when a plate press is available [J.J.B. Teuben]. A special punch is put on the press and profiles can be flanged. It requires more workers (machine operators, transporters) and transport however.

Just as plate folding, 10000 profiles can be formed per year. This is more than sufficient for the 200% production increase.

Profile forming/curving

Forming profiles can be done in different ways. At Damex a manual profile forming machine is available. By using molds the profile is formed in the desired shape. A faster, but more difficult way is to mark inverse curvature lines on the profile. The profile has to be formed until all the lines are straight. CNC and semi-automatic profile bending machines exist and are more productive.

Profile forming requires an area (inside building, machine + machine work buffer); workers (machine operators, transporters); transport crane; profile forming machine (Damex).

100 tons of profile can be formed by the profile forming machine per year. When production is to be increased by 200%, a maximum of 140 tons is required. This means that (under the current assumptions) a new profile forming machine is required when steel part processing are done in house under these conditions.

Profile grinding

When profiles are cut, sometimes the sharp edges have to be grinded. This is to ensure paint adherence. Moreover it reduces the chance of injury and thus the handling speed of the part.

Profile finishing requires an area (inside building or outside+ local work buffer); workers (grinders, transporters); transport (crane or forklift)

Just as small plate parts, 13000 profile parts can be grinded per year by one grinder. At the plate grinding section the profile parts are already taken into account.

Profile sorting

When profiles are prefabricated they are sorted for production. The same sorting rules and transport moves as for plates are applied for profiles. Sorting of profiles is generally done per profile bundle. This bundle consists of all profiles per panel.

Required resources are area (inside building or outside); workers (sorters, transporters) and transport (cranes or forklift)

Just as plates, 6600 profile bundles and small part crates can be sorted per year per sorter. At the plate sorting section, the profile parts are already taken into account.

4.5 Ship assembly

During ship assembly process the end product is built. This means that this process is the main value adding process of the shipyard. Ship assembly is a complex process, since many intermediate products have to be assembled before the end product is assembled. Also the intermediate products can differ significantly. More of this is explained in this section.

4.5.1 Process and resource description

From steel parts the steel panels and sections are produced. These sections are assembled to blocks or directly to a ship. Sections, blocks and the ship can be outfitted with hot and cold outfit parts and paint.

When all equipment in a system is fully installed, it can be tested (harbour trials). When all systems are tested the ship can be tested at sea (sea trials). When every test is finished the ship is commissioned. When the customer's requirements are met, the ship is delivered to the client in a ceremony.

Since the ship assembly process is the main value adding-, and by far the most labour intensive process, and contains the most problems, this process is the main focus of this research. The average of 95 and 105 direct ship assembly employees is 100, which is set as constant for this research.

4.5.2 Predictability at this process level

At this process model level, not much can be said to determine the required resources of the shipyard. The output of the shipyard, which can be the number of ships per year or the tons of casco steel per year (see chapter 1), can be determined. Also the total production area (including buffers, slipway and outfit quay) of the shipyard can be measured (22000 m2) or the total number man-hours (direct) per year (220000 mh). The total number of cranes and other transport and production machines can be determined (6 cranes, 2 big forklifts). These numbers can be used to determine a rough indication of overall productivity.

However it is impossible to determine how much workers, area, transport or production machines are required by these overall numbers. This black box has to be opened. This is done in chapter 5.

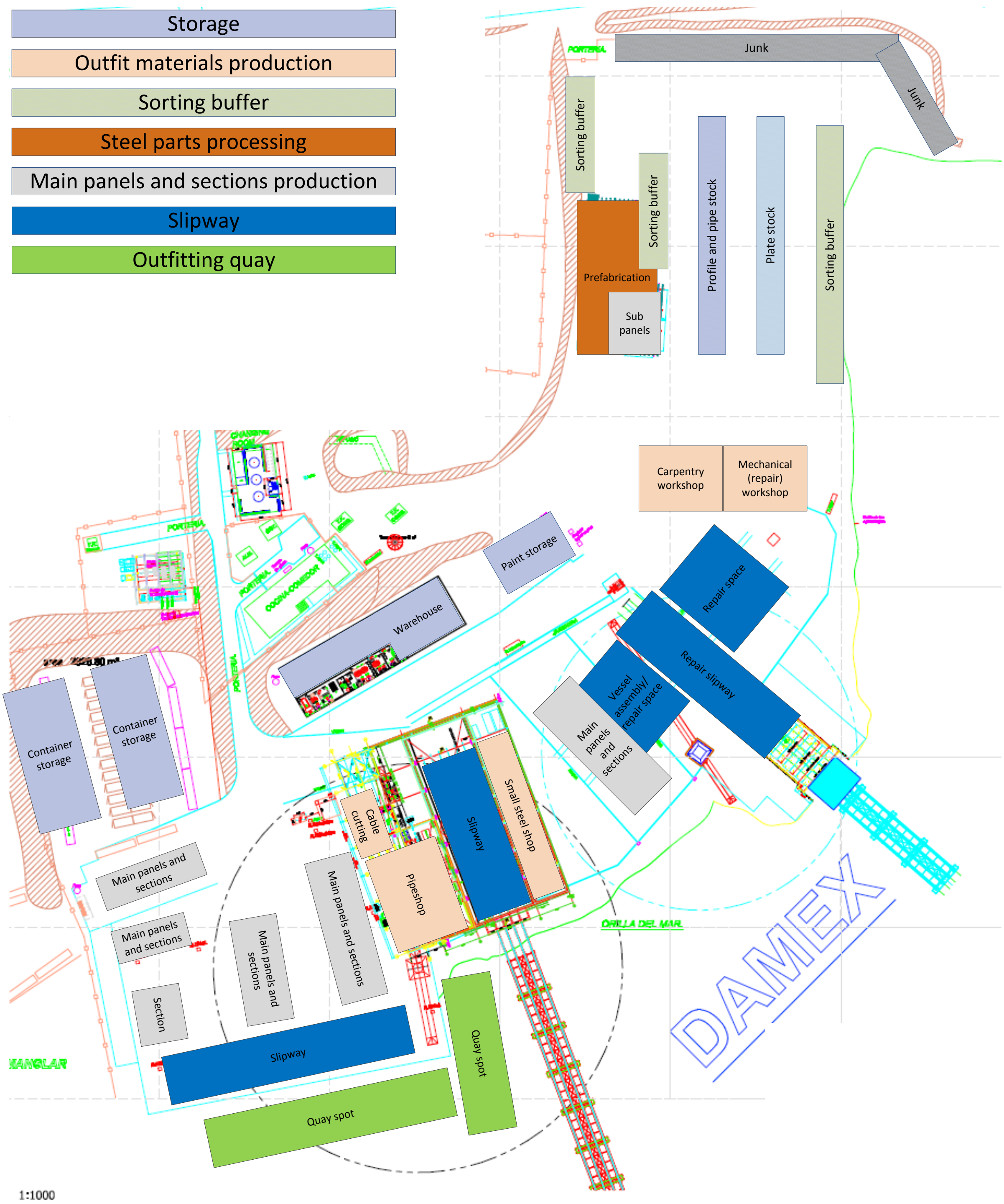

Figure 21. Damex current layout

4.6 Damex shipbuilding circumstances

Damex is located in Cuba. Cuba is a communistic country and has its own political, economical and cultural circumstances. These Cuban circumstances are described in this section.

The power from the power plant regularly fails. This means that the emergency generator sets are used frequently. However the electric frequency is wrong for the CO2 welding equipment, which means that only the electrode welding can be used. A new power grid and generators are currently being constructed.

Workers are paid in a communistic way: everyone receives the same reward for unequal delivered work, which does not encourage hard or accurate work.

Sometimes a bus with workers does not arrive because the bus is broken. Nothing can be done about this, since busses by definition are state property.

Painting is only being done by roller, except in tanks, since the Cuban management sees paint spraying as wasting paint.

The cranes do not always work. During my presence only two out of five cranes were operational.

There is a chance that the Cuban government claims machines of the shipyard for construction work. Therefore lifting equipment must not be too maneuverable.

Every tool, machine or material must be imported, and the supply lines are long. Sea transports cost 2-3 months and air transport 2 weeks (R. Kentie) and are highly irregular. This way DSGo is not able to fully control the inventory of Damex. Therefore a considerable local supply stock has to be maintained.

Outsourcing to local sub-contractors is basically non-existent. Companies at Cuba, which are state owned, cannot ensure the quality standards of Damen without regular Dutch quality control. This is hard enough at Damex alone. Therefore materials and equipment that cannot be produced at Damex is outsourced to the Netherlands.

All these circumstances ensure that the condition of production at Damex are not the same as those in the Netherlands. Therefore productivity cannot be exactly the same when using exactly the same resources.

4.7 Damex process analysis scope

As can be seen in the previous paragraphs, four main process groups take place at a shipyard. The most important process is the ship assembly process. At Dutch shipyards outfit material production and occasionally steel part processing and material stocking are outsourced to other trusted companies.

The main value adding process of the shipyard, and therefore the core business of a shipyard is the ship assembly process. Therefore this process is analyzed during this research.

Warehouse and outfit manufacturing processes are important and very interesting, but not core business and therefore not further analyzed. When production increases, the production of these processes have to keep up. Therefore the previously identified investment requirements are taken into account.

Steel and/or aluminum part processing is not part of the ship assembly process, because it is metal processing and not assembly. Also at various shipyards these processes are outsourced. At Damex metal parts fabrication is already part of the existing process, it is the start of the casco assembly process, finished parts can be sorted for their to-be intermediate product and it is much cheaper to perform these processes at Damex, since outsourcing can only be done in the Netherlands. Therefore metal parts processing is included in this research for the investment plan.

Conclusion: In this research the ship assembly process is analyzed and modeled, since it is the main value adding process of the shipyard. The feasibility of investing in steel/metal part processing is included in this research, since it is cheaper to do this at Damex than in the Netherlands. Investments in material storage and outfit materials production are included, since they have to keep up with the production increase of the ship assembly. An investment plan is made in this way.

5 DAMEX SHIP ASSEMBLY PROCESSES ANALYSIS

As explained in chapter 4 the ship assembly process is the main value adding process of the shipyard. The WBS of chapter 3 is assembled during this process. In this chapter all the indicated processes of the ship assembly are analyzed and modeled in accordance to the PROPER model, adjusted for the research scope: the ship assembly black box of chapter 4 is opened. The ship's parts are produced in several sub-processes. In this chapter the following secondary research questions are answered:

- **How can a shipyard production process be modeled into a system?**
- **What are the resources of the workloads of Damex' sub-processes?**

The former research question is answered further, because of the scope tightening in chapter 4. The latter one is answered following the modeling of the former research question.

First the overall ship assembly processes are described and modeled in accordance to the PROPER model. The current overall organization and those at other shipyards are described. After that the individual sub-processes are analyzed. Workloads (building the WBS) are described and their required resources are determined by modeling a simplified sub-process PROPER model, in other words opening the box. The current Damex sub-process resources and those at other shipyards are described.

5.1 Ship assembly process

In this section the ship assembly sub processes are introduced and its organization at Damex is analyzed.

5.1.1 Ship assembly sub processes

All the sub-processes which take place during ship assembly are closely linked to each other. All identified parts/(intermediate) products in the WBS are assembled and/or fitted during these processes by using specific resources. The coherence of the sub-processes is shown in the ship production model in figure 22. The current location of these processes are shown in figure 21 in chapter 4.

From figure 21 in chapter 4 can be seen that the current process layout, and therefore material flow, is not directly comparable with the process model in figure 22.

Currently all ship assembly sub-processes are performed outside by using field equipment. Working outside is cheap, but the process is prone for weather delays. Welding and painting cannot be done during rain. Rain is quite common in Santiago de Cuba: it rains 15% of the time (see section 7.5). Field equipment is versatile, but requires a lot of space to maneuver.

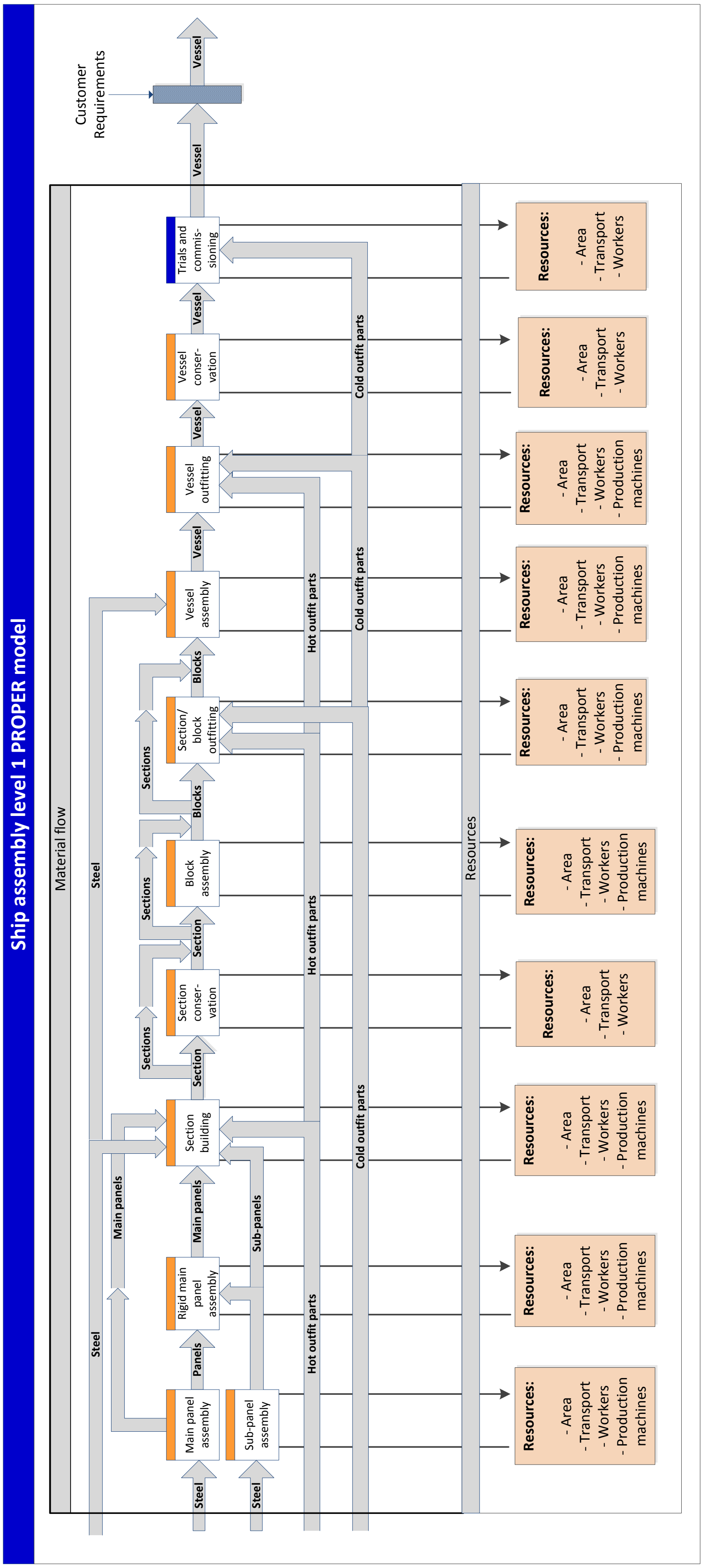

Figure 22. Ship assembly level 1 PROPER model

In principal all the sub-processes can be improved, except for trials and commissioning. Trials and commissioning is done roughly in the same way at most shipyards. In this research trials and commissioning is not investigated.

The following matrix-shaped representation can be identified:

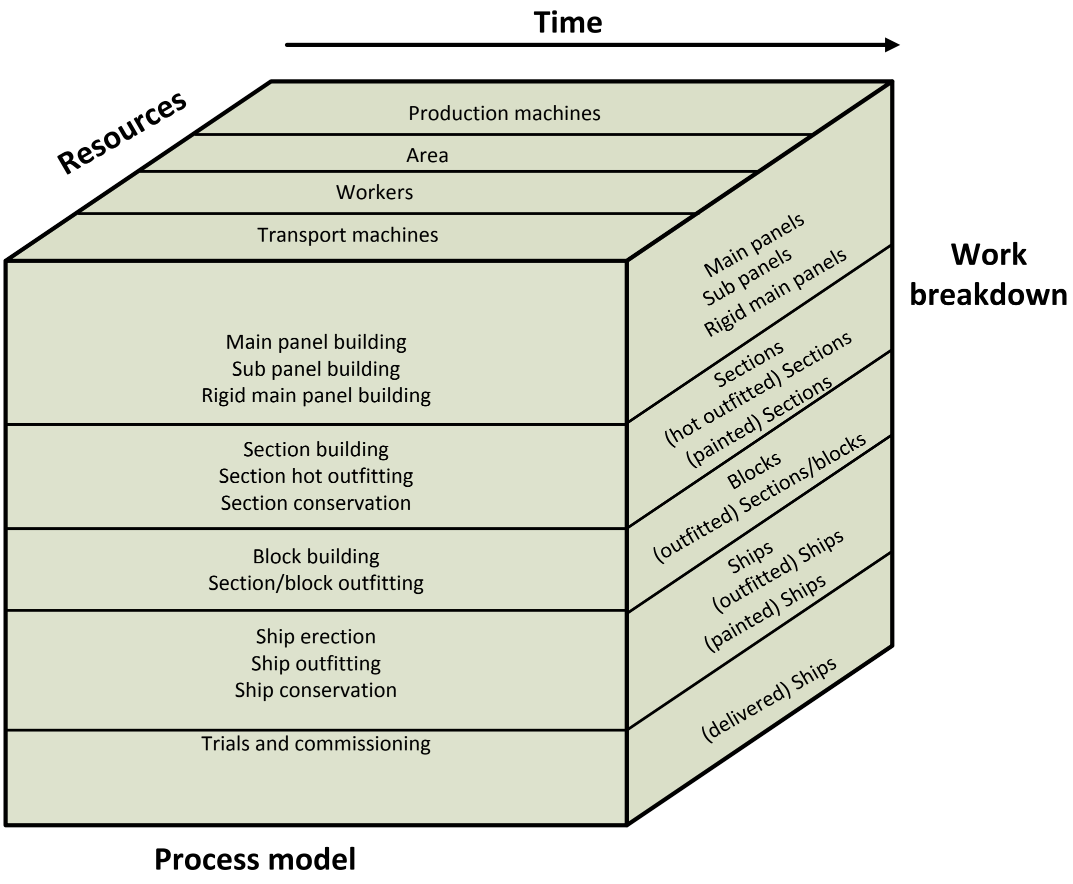

Figure 23. Ship assembly process matrix model representation

These two figures give a nice overview of the theoretical production order of intermediate products, and that several processes of producing intermediate products can take place at the same time.

5.1.2 Organization and layout

Shipbuilding is generally seen as a one-off, fixed position, project oriented business [2, 3]. However the assembly of several intermediate products can be seen as small series production. The following definitions are used by Slack [2]:

- Project process: Low volume, high variety (one offs), big and products are difficult to move. Devoted resources per product
- Jobbing process: Significant variety in products; products require similar but different processing. Skilled workers usually required. Shared resources per product

Slack also gives batch process, mass production process and continuous process, but these are not relevant for the shipbuilding capacity at Damex. Different processes require different layouts.

The relations are clearly shown in figure 24.

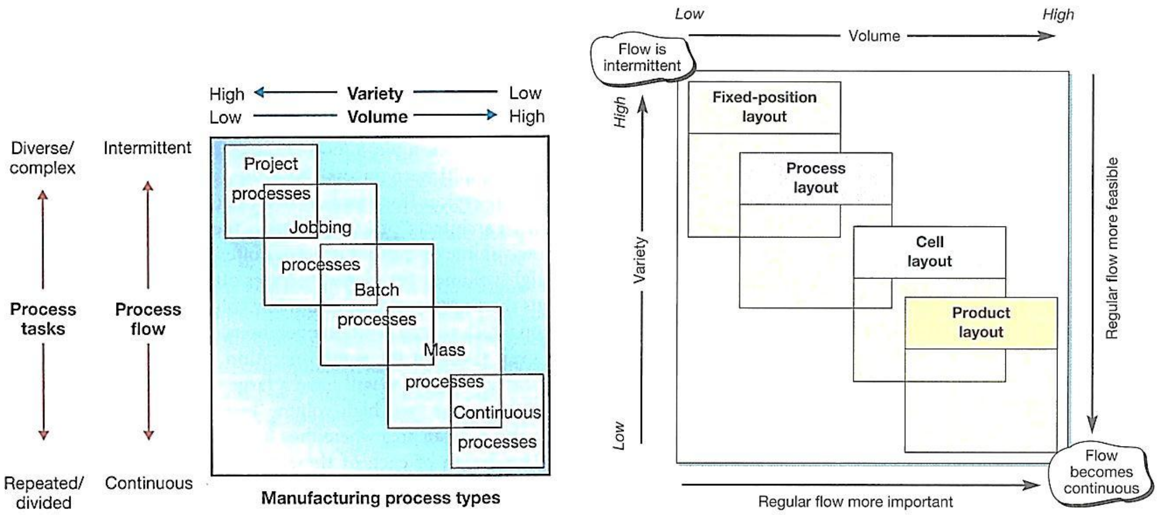

Figure 24. Process, product and layout relation (Slack [2])

Currently at Damex most ship assembly processes are arranged as project processes, except for the sub panel production, which is arranged as a jobbing process.

This overall knowledge is not enough to determine what is an optimal layout regarding cost efficiency for Damex. To gain more knowledge about the ship assembly sub-processes, in the following paragraphs the sub processes are analyzed.

5.2 Panel building

Panels are 2D stiffened plate(field)s. Panels are generally built horizontally to enable down hand welding. Down hand welding is the easiest and fastest way of welding. Preferably panel production is done under factory conditions.

5.2.1 Main panel building

Main panels are profile-stiffened plate fields. At Damex they are built manually. The plates are positioned by using a crane, aligned and tack welded manually and welded by a submerged arc welding (SAW) tractor. The plate field has to be welded on 2 sides, so it has to be turned. After this the plate field is fixed to the building beds by tack welds. Profiles are positioned by using a crane, aligned and tack welded manually. Welding is done by using CO2 or sometimes electrode welding equipment. It happens during the rigid main panel and section building phase (Damex sees this whole process as section building). The reason for this is (according to Damex) less deformation problems.

Figure 25. Damex submerged arc welding

At other shipyards (DSNS, DSGa) highly mechanized panel lanes are used. These panel lanes have a different work station for each described process step. Tooling is optimized for each process step to minimize setup time.

Positioning plates or profiles is done by using specialized magnetic transport yokes and clamps.

Plate field welding can be done one sided by the SAW tractor in combination with a cooling clamp at the bottom of the butt weld. This is a feature of a mechanized panel lane. Profile welding is done by dual gun fillet weld tractors during main panel building. The welding is done under hand and mechanized this way. This reduces welding hours, but primarily assures quality. Deformations are kept in check by fixating the plate field with magnets.

At more advances shipyards welding robots are used to even further reduce welding hours. Sometimes laser welding is used. This is done primarily to reduce deformations, since less heat is put into the steel.

The plate-field and panels are transported to each station by a hydraulic roller track.

The main disadvantages of a panel lane are the inflexibility and the investment. Since the panel line consists of successive work stations panels must be very alike, or else waiting times increase. This is shown in figure 26. A balanced cycle time is very important for a mechanized panel lane to pay off. The investment of such a machine is in the millions of Euros.

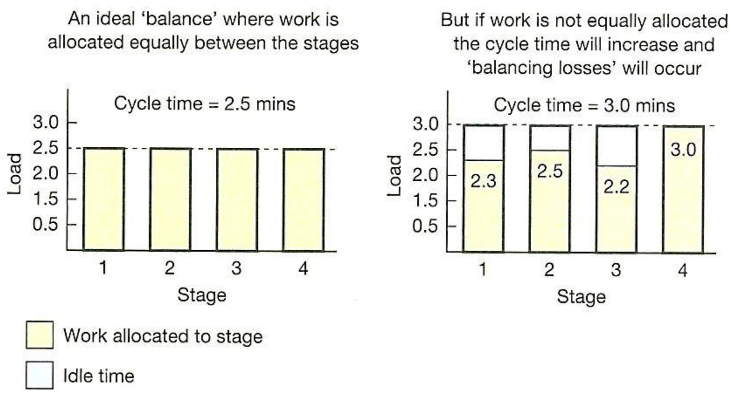

Figure 26. Balanced cycle times (Slack [2])

Currently the main panel production takes place outside. This causes weather to have a big influence. Workers are unable to work hard in the sun and are completely unable to work in the rain. More of this is described in chapter 6.

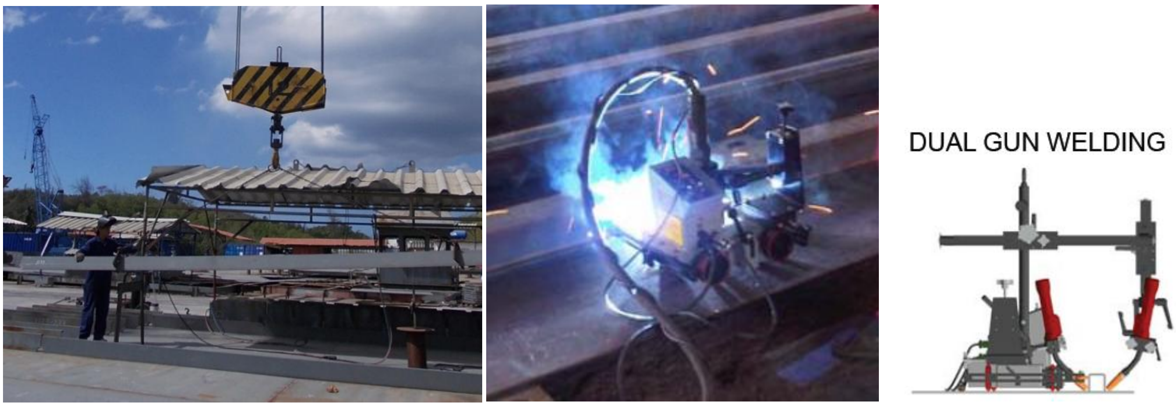

Figure 27. Damex panel part positioning and dual gun mechanized profile welding (Gullco Moggy [27])

Welding is the most important action in casco building. The most efficient way of welding is welding down hand. Down hand welding is a known productivity factor and therefore a current practice at Damex. Therefore this will not be elaborated any further in this research. The whole casco building process is done in such a way that the welders can weld down hand. This is the reason why panels are built (see panel building appendix A) and why sections are built upside down and later turned (see section building appendix B).

Welding can be done manually, mechanized, automated or even robotized [15].

Table 11. Welding methods

Manual (semi-automatic) welding	Mechanized welding	Robotized welding systems
Flexible positioning	Semi-flexible positioning (carriage way required)	Fixed positioning
Low set up time	Low set up time	Initial high set up time, during production no set up time
Low investment	Low investment	High investment
Average welding speed, one weld torch	Average welding speed, one to two weld torches	Average to fast welding speed, multiple weld torches
Labour intensive	Less labour intensive	Capital intensive
Weld quality depends on skill of welder	Weld quality constant	Weld quality constant

Main panel building requires area (inside building or outside); workers (panel builders, welders, transporters); transport (crane or forklift); production crane.

Data from Damex gives that 2 panel builders and 2 manual welders work roughly the same time (55% building, 45% welding). This division also appears from old costing data of Dutch shipyards. The throughput time depends on the welding meters per panel, and therefore the area of the panels and the number of parts per panel area [14].

- Hours per panel area is used as estimator for the throughput time and man-hours.
- The average panel area per ship is used for time and man-hour estimation.

The area is determined by the panel area, the number of panels that are being built simultaneously and the duration of the panel building, welding and possible waiting.

- For area estimation when building simultaneously, the average main panel area + one standard deviation is used. This is done in order to mitigate the effects of panel area fluctuation due to the large variety of main panels.
- The number of simultaneously built panels is determined by Little's Law [6].
- In- and output buffers are used. The input buffer comprises a stack of plates and profiles. The output buffer comprises the biggest main panel.
- Waiting time per panel is unknown. Compared to Dutch shipyards panel building and welding hours are very high. Since Dutch and Cuban welding machines have the same working principle, the overall difference is mainly considered waiting time.

The number of cranes is determined by when a crane move is required and the duration. Parts of more than 50 kg are considered to require a crane. For main panels these are plates and profiles. In figure 28 the level 2 process model of main panel building is shown. In this model it is shown when cranes are used.

- Production crane for positioning of plates and profiles.
- Heavy transport crane for moving the assembled main panel and for turning the plate field

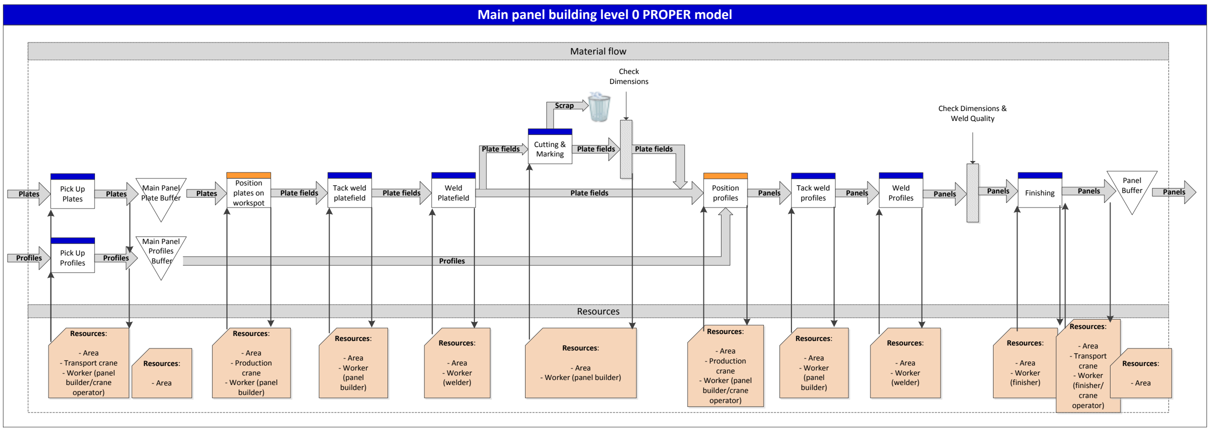

Figure 28. Main panel building level 2 PROPER model

A detailed resources overview is shown in figure 29. The possible waiting moments for cranes or welding machines are also shown in grey. When too few of these resources and facilities are available, this can have big consequences.

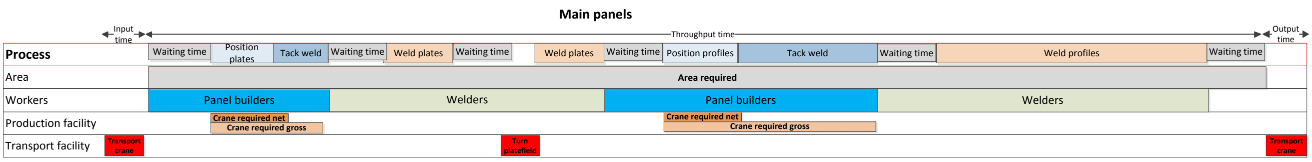

Figure 29. Main panel building level 2 resource overview in time

A clearer version of this model can be found in appendix A.

However, since the overall sum of much precise data is the same as the sum of the average of the same data, for the calculation this level of detail is too precise.

For an average main panel of a Stan Lander 5612 of 34,8 m2, which contains 0,63 parts/m2, the duration is one week (44 work hours), which means 24 hours of panel building and 20 hours of welding. Given 2 workers per process, the total is 88 man-hours.

For this man-hour estimation, the 1 welder for mechanized SAW welding, which means 25% of the welding hours (half of half the welding hours) reduction is already taken into account.

When dual fillet welding tractors are applied, another 25% (half of the other half of welding hours) of the total, which currently means 33% of the remaining welding hours, is saved.

Generally speaking, panel production is calculated in the following way:

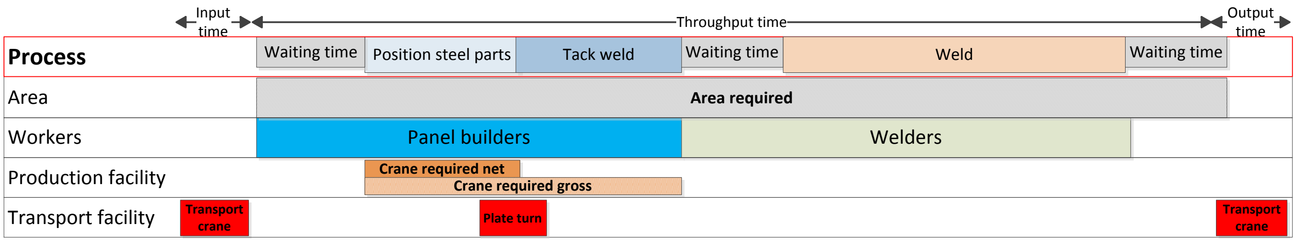

Figure 30. Simplified main panel resource overview

The waiting for cranes, working tools or good weather is a big problem at Damex. Also assembly accuracy and welding deformations are a serious problem. This is a major cause of rework hours. More of this is described in chapter 6.

5.2.2 Sub panel building

Sub panels are smaller panels, consisting of one plate and one or more profiles. The sub panel is to be mounted on a main panel, hence the name sub panel. A distinction is made between T-sub and plate sub panels. At Damex normally (small) sub panels are centrally built manually next to the plate prefabrication shed. Currently due to circumstances this is not possible so they are built at a provisionary workshop near the section building area.

For a T-sub, positioning the plate and profile a production crane is required. Tack welding and welding are done manually. For a plate sub a crane is required only for positioning the plate.

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Figure 31. Damex plate sub building and T-sub building

At other shipyards sub panels are assembled and welded centrally at a specialized sub panel build location, sometimes at a special sub panel lane. Welding is performed under hand. Welding can be mechanized by using fillet weld tractors. T-sub assembly can also be mechanized by using a clamping machine. At some big shipyards sub panel building is completely robotized. The previously mentioned disadvantages of balanced products and high investment also apply here.

Required resources are: area (inside building or outside); workers (panel builders, welders, transporters); transport cranes; production cranes or sub panel assembly machine.

- These resources are determined in the same way as main panel building.

The waiting for cranes, working tools or good weather is a big problem at Damex. Also assembly accuracy and welding deformations are a serious problem. This is a major cause of rework hours. More of this is described in chapter 6.

More information regarding sub panel building can be found in appendix A.

5.2.3 Rigid main panel building

Rigid main panel building is the process of mounting and welding the sub panels on a main panel. Sometimes this process is seen as main panel building and sometimes as section building. So in this research it is considered to be a separate process.

Figure 32. Damex rigid main panel building and welding

The sub panels are positioned by using a crane, tack welded and welded (CO_2, sometimes electrode) manually on the main panel. Only at highly automated Japanese shipyards robotized welding of rigid main panels is observed. The previously mentioned disadvantages of balanced products and high investment apply here even more.

Required resources are: area (inside building or outside); workers (panel builders, welders, transporters, finishers); transport cranes; production cranes.

- These resources are determined in the same way as main panel building.

The waiting for cranes, working tools or good weather is a big problem at Damex. Also assembly accuracy and welding deformations are a serious problem. This is a major cause of rework hours. More of this is described in chapter 6.

More information regarding rigid main panel building can be found in appendix A.

5.3 Section production

Sections are 3D shaped interim constructions. Sections are constructed horizontally, preferably under factory conditions. Sections are considered the first parts able to bear hot outfit parts at Damen.

5.3.1 Section building

The definition of a section is a box shaped 3D object, made of (rigid) main panels, sub-panels, plates and profiles. There are several types of sections.

- Closed straight sections
- Closed curved sections
- Open straight sections
- Closed straight sections

Section building can be done in many different ways. At Damex the building process of a section is usually started in building position (upside down) with a (rigid) main panel. The secondary main panels, sub panels, plates and profiles are positioned on it (in that order), if required by using a crane, and tack welded. This is only for the down hand and vertical weld parts. When this is done the section is welded down hand and vertically. Next the section can be pre-outfitted with some hot outfit materials.

When the pre-outfit items are installed the section is closed by positioning and tack welding the closing main panel and/or plates. This happens above head. When this is done the section is turned to its upright position. When required more plates and profiles can be mounted and the remaining un-welded parts of the section can be welded. Remaining pre-outfit items are installed and the section can be finished by grinding edges that are to be painted and straightening deformed parts.

Figure 33. Damex section building

This process is also observed at other shipyards. Not much automation is observed during section building.

Bigger shipyards may have separated production locations and tooling for each section type [4]. This is to reduce the variability of section building. Curved sections have relatively more and more complicated parts than straight sections. Their production time is longer and they are heavier, generally speaking.

Required resources are: area (inside building or outside); workers (section builders, welders, transporters, finishers); transport cranes; production cranes.

These resources are determined in the same way as main panel building, with some exceptions:

- The throughput time of sections is estimated by hour/ton instead of hours/m2, since a section is a 3D construction. This is between certain plate thicknesses bandwidths. Tugs and workboats are generally heavily constructed and are in the same bandwidth, but high speed craft are lightly constructed. To make these two bandwidths comparable, calculations for high speed crafts are done with equivalent tons.
- Throughput time is dependent on the parts per (equivalent) ton instead of m2, since a section is a 3D construction.
- Production crane times can differ more. Positioning a vertical main panel takes longer than the positioning of a profile.

Section building is calculated in the following way:

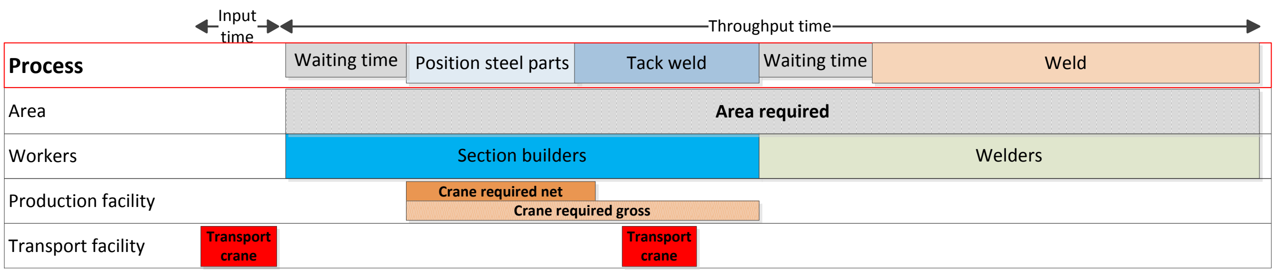

Figure 34. Simplified section building resource overview

The waiting for cranes, working tools or good weather is a big problem at Damex. Also assembly accuracy and welding deformations are a serious problem. This is a major cause of rework hours. More of this is described in chapter 6.

More information regarding section building can be found in appendix B.

5.3.2 Section hot outfitting

Section pre-outfitting before section conservation means mounting and welding the hot outfit materials in the section during section building. The process takes place during section building, because there is hot outfitting before and after the turning of the section and there is also section building before and after the turning of the section [4]. So they are considered as one process in the process model. During pre-outfitting in building position (upside down), when the section is still opened from above, spaces near the ceiling of the section are more accessible, also by crane, than in upright position. This means it saves scaffolding and horizontal hoisted moving time (when the section is closed from above) when already in upright position.

Figure 35. Damex section hot outfitting

There is general consensus in shipbuilding that as much (hot) pre-outfitting is to be done as early in the process as possible: *'Completing outfitting earlier allows the work to be done in better conditions. If outfitting work is done in better conditions, in a less cluttered environment, such as in a work shop, it can be done with fewer men in less time with better quality and corrosion prevention; thus the work is done more efficiently. All this leads to the reduction of time and cost.'* [20]

However, the accurate system information is required at this early stage. This means that engineering of the systems must be ready well before section building, or even plate cutting. It is several shipyards' experience that production wants to start when the engineering is not completed yet [DSNS, Bergej Shipyard, DSGo, Damex]. This results in unnecessary rework in awkward positions during ship outfitting, which costs more man-hours.

The main disadvantage is that section pre-outfitting takes place during section building, and so more resources are required during this phase of the process. This means that more area, workers, transport and production machines are required during this phase.

Currently there is a considerable percentage of hot outfit installed during section building. The table 12 shows the total number. The numbers are based on experience of Damex management.

Table 12. Current outfit distribution percentage

	Section outfitting	Block outfitting	Dry ship outfitting	Wet ship outfitting
Hot outfit (%)	50	n/a	50	0
Cold outfit (%)	n/a	n/a	65	35
Paint (%)	0	n/a	100	0

Section pre-outfitting requires an area (in or outside a building); transport (forklift or crane); production cranes; workers (specific fitters)

- The area is dependent on the throughput time, which again is dependent on the amount of hot outfit parts, their specific throughput time and the number of hot outfitters. At Damex observations show that 2 to 6 hot outfit fitters can be working per section.
- The number of cranes is dependent on the number of hoist moves, which is dependent on the number of hot outfit that is fitted during this phase that is heavier than 50 kg.

This results in the following representation for calculation:

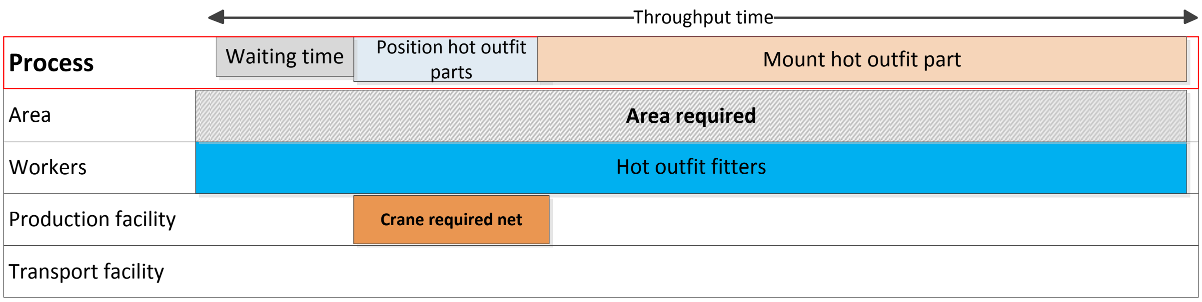

Figure 36. Simplified section hot outfitting resource overview

The waiting for cranes, working tools or good weather is a big problem at Damex. Also assembly accuracy and welding deformations are a serious problem. This is a major cause of rework hours. More of this is described in chapter 6.

More information regarding section pre-outfitting can be found in appendix D.

5.3.3 Section conservation

When section building and the hot outfit works in this section are finished, the section can be painted. First the section is grit/sand blasted and cleaned, since corrosion and production waste is not beneficial for steel conservation. When properly cleaned, the steel is painted with primer (sometimes called minium by production) [R. Kentie]. Next, two layers of epoxy paint is put on, but not the final coating since it can be damaged during production [Ger Koerts, Akzo Nobel surveyor]. It is important that at least the foundations (for equipment, cables, pipe spools etc.) are properly painted before their equipment is installed.

Currently at Damex it is not common practice to paint the sections after pre-outfitting. Occasionally they are painted in primer, but this was not observed during my stay. The current amount of painting after section building is shown in table 12.

Sections are produced outside. During rain it is impossible to blast or paint sections. This is a big problem, since painters have to wait for better weather. In Santiago de Cuba there is rain for 15% of the time (see section 7.5).

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Figure 37. DSGa section conservation (DSGo database)

At other shipyards (DSNS, DSGa) painting of pre-outfitted sections is widely accepted and used. Sometimes a specialized painting hall is available. This painting hall is specifically equipped for grit blasting, paint spraying and has a controlled climate for fast drying. A specialized paint hall requires a big investment and extra transport means.

A cheaper way is to isolate the section in foil and paint it inside the hall. However this has to be done when there are no other workers present inside the hall, since painting fumes are very unhealthy. This usually means they have to work in the evening or during weekends.

Some places of the section have to remain unpainted, because welding is still required there.

The main disadvantage is that section conservation takes place during section building, and so more resources are required during this phase of the process. This means that more area and workers are required during this phase.

Required resources are: (protected) area (inside building or outside); workers (painters, transporters); section transport facilities.

Cleaning and painting a section takes 30% less time per surface treatment (blasting or painting one layer) than treating the same surface during ship conservation (R. Kentie).

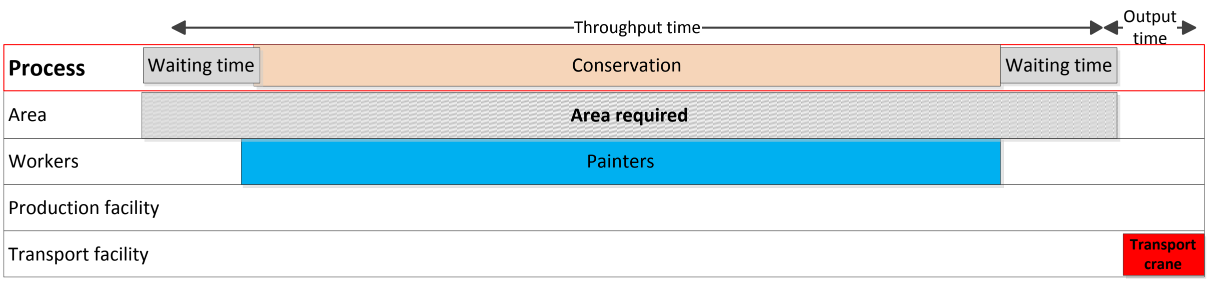

Figure 38. Simplified section conservation resource overview

More information can be found in the section conservation appendix F.

5.4 Block production

Block is an interim phase between section and ship. Blocks are able to bear hot and cold outfit and paint.

5.4.1 Block building

A block is defined as a composition of one or more sections in upright position, and is generally used to reduce the amount of time it takes to assemble a ship on the slipway or to 'minimize hull erection work' [5]. These blocks comprise the whole breadth and depth of the ship. Blocks can be divided in:

- Bow blocks
- Aft ship blocks
- Mid ship blocks
- Engine room blocks
- Accommodation blocks
- Wheelhouse blocks

Each type of block has its characteristic form and function. The function of a block refers more to the outfit of the block. At Damex blocks are rarely produced. Due to the size of the block the crane is not always able to lift it. Block building requires good measurement control.

First the primary section is positioned at the block building station. After that the secondary sections are positioned. Sections edges are fit by cutting excess steel and beveled for butt welding. Fulcrums are fixed by tack welding temporary plates. After the fulcrums are fixed, the crane is no longer necessary and the following connecting section can be positioned. During fixing the next section the previous sections are fully tack welded and welded to the block. Welding is currently done by CO2 welding in combination with ceramic weld backing.

Figure 39. Damex bare block building and outfitted blocks at Korean shipyard

Assembling blocks from fully painted and pre-outfitted sections is not current practice at Damex. At other shipyards (DSNS, DSGa) blocks are built from fully painted and pre-outfitted sections. The reason for this is the previously mentioned reduction of hull assembly time at the slipway, but also the opportunity to begin with installing remaining hot outfit, and cold outfit in the blocks.

Welding can be done manually, or by magnetic welding tractors. Both welding happens in combination with ceramic welding backing. Mechanized welding provides welder independent welding quality, which may reduce rework welding hours.

Required resources are: area (inside building or outside); workers (section/block builders, welders, transporters, finishers); transport cranes; production cranes.

Resources are generally determined the same way as in section assembly. The waiting for cranes, working tools or good weather is a big problem at Damex. Also assembly accuracy and welding deformations are a serious problem. This is a major cause of rework hours. More of this is described in chapter 6.

More information regarding block building can be found in appendix C.

5.4.2 Block/section outfitting

Block/section outfitting is installing the (if) remaining hot outfit, and cold outfit in a painted block or section. At Damex currently neither block building nor block/section outfitting is done.

At other shipyards (DSNS, DSGa) block/section outfitting is common practice. In fully hot outfitted and painted blocks or sections cold outfit is installed. This happens in this phase because a block or section is still open on at least one side. When a crane is required to lift heavy equipment in the block, the block is to remain open at the top. This has to be taken into account when determining the building strategy.

Compared to ship outfitting it is relatively easy to lift and fit equipment in during this phase because of the accessability of the open block on the floor.

The main disadvantage is that section/block outfitting takes place after section/block building, and so more resources are required during this phase of the process, instead of at the slipway or outfitting quay. This means that more area, workers, transport and production machines are required.

Block outfitting requires an area (in or outside a building); transport (forklift or crane); production cranes; workers (specific fitters)

Resources are generally determined the same way as the section pre-outfit, except that painting and fitting cold outfit also can take place. This results in the following representation:

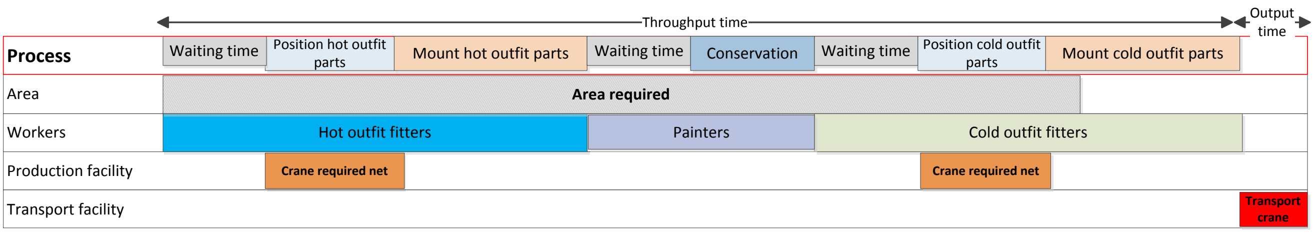

Figure 40. Simplified section/block outfitting resource overview

The waiting for cranes, working tools or good weather is a big problem at Damex. Also assembly accuracy and welding deformations are a serious problem. This is a major cause of rework hours. More of this is described in chapter 6. More information regarding block outfitting can be found in appendix E.

5.5 Ship erection and outfitting

In this phase the ship obtains its final shape. During the assembly at least its heavy equipment can be fitted. Assembly, outside conservation and fitting of heavy equipment is generally done on the slipway. The rest can be done at the outfitting quay.

5.5.1 Ship erection

Ship erection is the last stage of the casco building process. Ships are erected from blocks and/or sections, plates and profiles. At Damex ship erection is currently done at a transverse slipway. In the near future it will be done at the covered slipway, which is currently under construction.

Currently a partly pre-outfitted, unpainted section, or sometimes block, is positioned at the slipway. Preferably this will be an engine room section or block, since they contain the most outfit, and therefore require the most outfitting time [4]. The next section is temporary positioned next to the previous section and fit by cutting excess steel. The cut plate edges are beveled, and the section is pulled to the ship by using cranes and manual jacks. When the section is in final position, its fulcrums are fixed by tack welding temporary plates. After that the rest of the section is tack welded and welding bridges are positioned. When the section is fixed, the crane is no longer required and the next section can be assembled to the previous one. When the sections are fixed and tack welded, finally the section is welded. Welding is currently done by CO_2 welding in combination with ceramic weld backing stones.

Figure 41. Ship erection at Damex outside (Damex database) because of small door

This process is done at the most shipyards in roughly the same way. When measurements control is lacking, positioning and fitting the sections/blocks to each other correctly (particularly with curved sections) is time consuming since a lot of excess material has to be cut off [4]. Possibly the section has to be adapted a bit. Other shipyards use hydraulic jacks and cranes for aligning the sections/blocks, since hydraulic jacks are faster and less labour intensive than manual ones. Welding is done by magnetic welding tractors. Welding mechanization ensures weld quality, which reduces rework.

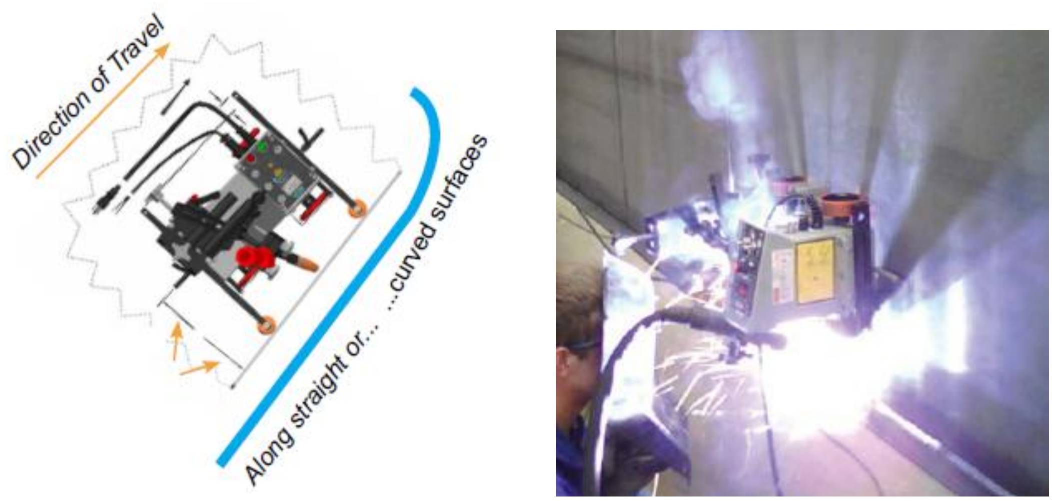

Figure 42. Mechanized shell butt welding (Gullco Moggy weld carriages [27])

Required resources: area (inside slipway or outside); workers (ship erecters, welders, transporters, finishers); transport cranes; production cranes.

Resources are generally determined the same way as block building. When ring sections or blocks are to be assembled the, man-hours per ton ratio is not necessarily a good way to predict the man-hours and throughput time. This is because the weld meters are not 3D, but 2D in that situation. However, since the calculations are done based on average section and blocks, it can be used when making a distinction between sections and blocks. Sections and blocks can be placed on two sides of the original block or section during ship erection, which enables concurrent work. The number of sections per block is also a parameter, since these sections can be stacked, while blocks can only be placed next to each other. This creates more concurrency.

For Damex it is initially assumed that the ship is fully erected at the slipway before it is launched. In reality this is not always the case, since accommodation is sometimes placed after launch. Therefore the outfitting quay must remain accessible for the heavy mobile crane to lift the accommodation on the ship in the water.

Currently the indoor slipway is not being used, because the slipway is still under construction and the door is too small for sections to move in. Also there is no transport machine available that can transport sections inside.

Damex has at least 2, and possibly 3 available slipways. Compared to other shipyards this is quite a lot. This is not a bottleneck for the production process. When the production is increased by 200% this might become a problem. The slipway data is shown in table 13.

Table 13. Damex slipways data

Slipways	l (m)	b (m)	lifting capacity (tons)	max weight ship (ton)
Slipway 1 (covered)	60	16	40	600
Slipway 2 (outdoor)	100		100	>600
Slipway 3 (repair, outdoor)	40		100	200

The waiting for cranes, working tools or good weather is a big problem at Damex. Also assembly accuracy and welding deformations are a serious problem. This is a major cause of rework hours. More of this is described in chapter 6. More information regarding ship erection can be found in appendix C.

5.5.2 Ship outfitting

During ship erection, ship outfitting takes place. At Damex, first the remaining hot outfit is installed. In an unpainted, top open casco, painted foundations are fitted and welded. Big equipment is lifted and mounted on these painted foundations. After that, the top sections are positioned over the top open casco, mounted and welded. During this time the rest of the hot outfit is completed. After that, most of the conservation is done. Finally the rest of the cold outfit is installed and systems are connected. When systems are completed, they can be tested.

All this work can be done at the slipway or at the outfitting quay. Outfitting of big equipment on the slipway happens during ship erection, since the hull is still opened. When ship erection is completed, some required underwater cold outfit (shafts, propellers, rudders, thrusters etc.) are installed and underwater (in- and outside) conservation processes are completed, the ship can be launched and wet ship outfitting can commence at the outfitting quay.

Figure 43. Damex (closed) ship outfitting

Figure 44. Damex (open) ship outfitting

Wet ship outfitting at the quay is less efficient than at the slipway, especially with small Damen ships (only small stairs are required for entering and exiting the ship), but is required when the slipway is the production bottle neck.

Ship outfitting at other shipyards (DSNS, DSGa, DSGo) is done per space. This means that e.g. the engine room is fitted independently from the wheelhouse.

Ship outfitting requires an area (in or outside slipway; outfitting quay); transport (forklift or crane); production cranes; workers (specific fitters)

Resources are generally determined the same way as block outfitting. Current resources of the outfitting quay are:

Table 14. Damex outfitting quay data

Outfitting quays	max length (m)	lifting capacity (ton)
Outfitting quay	100	10

The waiting for cranes, working tools or good weather is a big problem at Damex. Also assembly accuracy and welding deformations are a serious problem. This is a major cause of rework hours. More of this is described in chapter 6. More information regarding ship outfitting can be found in appendices D and E.

5.5.3 Ship conservation

When the ship erection is completed, the conservation of the casco can be completed. The outside of the ship can be painted as a whole, as can the bigger tanks. At Damex, when this ship is being assembled, most of the ship is sand/grit blasted and painted with primer. After that outfitting and painting will be done concurrently per space, since there almost no painting of prefabricated casco parts. During this phase both layers of the epoxy paint are applied.

Figure 45. Damex outside hull and inside tank conservation

When the underwater hull (inside and outside) is fully painted, it can be launched. A fully applied conservation system of steel is at least 200 micron, which corresponds with 4 layers of paint (G. Koerts). This means that, including blasting, all surfaces need 5 treatments.

Figure 46. Damex completed hull painting at slipway (Damex website)

At other shipyards sections and blocks are already painted with one layer of primer and two epoxy layers. This means that the conservation system merely has to be finished after ship erection by applying the final layer. This saves painting hours, since painting can be done in less awkward positions.

Required resources are: area; workers (painters)

Painting of both spaces and outside is dependent on the surface that has to be painted, which are the bulkheads, decks and shell.

The waiting for good weather is a big problem at Damex. This is a major cause of rework hours. More of this is described in chapter 6.

More information regarding ship conservation can be found in appendix F.

6 SHIP ASSEMBLY RESOURCE ESTIMATORS AND DATA

A ship assembly system model is established in chapter 5, and the workloads and their resources have been determined. Since a new future capacity is required, it is important to know how to predict the future with this process model. Therefore in this research the following secondary research question is answered:

- **How can the resources of Damex' sub-processes be calculated?**

To answer this question, first equations and parameters for resource estimators have to be derived. By using the ship assembly process model, it is known when which resource is required in the process of building an intermediate product. In this chapter the 'for how long' and 'how many' per intermediate product and per year is determined.

6.1 Ship assembly resource estimators

The goal of this analysis is to determine the required resources (area, man-hours, transport and production machines) of the shipyard. In section 5.6 is shown when each resource is required in each process. In this section is explained how they are calculated.

First the number of products that is to be produced per year, or shipyard capacity, is established. Following this, the sub-processes' capacities are set as the parts required for those ships per year.

Different ships require different resources. Since the number of employees is initially considered constant (see chapter 1), the capacity of ships per year depends on the ship type. The number of man-hours per ship generally depends on the weight of the ship [5], but also on the complexity [16]. Since a Stan Lander 5612 is less complicated than a Stan Tug 2208, more can be produced relatively to the weight. Plate thickness is also a factor to consider. The weight of a Stan Patrol 4207 ship is comparable to a Stan Tug 2208, but requires a lot more work since it is a bigger ship, built with thinner plates.

Considering outfit, the average throughput time per hot or cold outfit item per phase is used. This average depends on the ship type, since big equipment requires more time than small, and one ship has more big equipment than the other; or spaces inside the ship are very small or sufficient to move. These times are stated in appendices D and E.

6.1.1 Estimators for production time, machines and man-hours

The main calculation that is used in this research is Little's law. All fabricated parts in a specific process have an average throughput time. Little's law states that the Work in Progress (concurrency of work per process) depends on the total throughput time per product divided by the cycle time per product, or the Production Capacity depends on the Work in Progress divided by the Cycle time[6]. The cycle time in this case is one year. The total throughput time is the average throughput time per part multiplied by all the parts that are to be produced per year in the specific sub-processes.

According to Storch [5] there are two methods of establishing throughput time: historically established productivity indices and engineered labour standards. Productivity indices are shipyard specific and the most reliable. In the absence of historical data, engineered labour standards are used. These engineered labour standards comprise the actual (theoretical) process time and the non-process time. Process time comprises the time the actual process takes place and non-process time comprises waiting time, personal time etc.

In this research both historical data and engineered labour standards are used. Since the aqcuired data does not comply with an average of each shiptype part, the required throughput times are estimated by using estimators.

The following estimators are used for calculating the required data.

Table 15. Productivity estimators

Process	Estimators	Estimators dependent on
Panel building	Hours/fabricated panel area [14]	Parts/panel area, steel thickness [14]
Section and block building	Hours/fabricated weight [5]	Parts/weight, equivalent weight [14]
Ship erection	Hours/assembled weight [5]	Sections or ring blocks, equivalent weight [14]
Hot and cold outfitting	Hours/item [appendices D and E]	Phase of process, ship type
Painting	Hours/weight/layer	Application during phase of process, sections or ship, equivalent weight

Panel building: For panel building the productivity index hours/produced weight [5] can be used, but the index hours/panel area gives a better prediction [14], providing the parts/panel area remains the same. The hours/panel area index is proportional to the parts/panel area index [14]. This relation results from the fact that varying in plate thickness results in a bigger variance in weight than required production hours: building a panel of 11 mm does not require 10% more time than a panel of 10mm. The parts/panel index is used because every part requires assembly and welding. When less parts are to be assembled and welded for the same panel (for example when the frame spacing is increased, or when bigger plates are used), it will take less time.

The workers involved in this process are panel builders and welders. Data show that panel builders require 55% of the hours and welders 45%. Currenly at Damex for sub panels one of each workers is required, and for (rigid) main panels two of each are required.

Section/block building: For section and block building the index hours/produced weight is used [5], providing the parts/produced weight remains the same. The hours/produced weight index is proportional to the parts/produced weight index [14]. Sections and blocks are 3D constructions and the increase in weight is a good indication of the progress of the assembly of a 3D construction[5]. Like in panel building, when the parts/produced weight increase, the hours/produced weight will increase because of the required assembly and welding.

The relation is valid when the thickness of the plates is comparable, since the assembly of a section of 12mm will not necessarily take twice as long as the assembly of the same section with 6mm plates. This is the case for comparing the Stu2208 and Sla5612 with the Spa4207. Therefore a steel thickness correction is applied to make the ships comparable. Concerning time estimation, the Spa4207 produced weight is corrected for the plate thickness.

The workers involved in this process are section builders and welders. Data show that section builders require 55% of the hours and welders 45%. Currently at Damex for sections and blocks two of each are required.

Ship erection: For ship erection the index hours/assembled weight is used [5], again corrected for plate thickness. During ship erection there can be a great amount of parallel working. When beginning erection in the middle of the ship, sections/blocks can be placed in two directions (to the front and aft), and can be stacked when there are many sections in a ring block. As explained in section 5.6 the following section can be attached when the fulcrums are fixed by temporary plates (section is not fully tack welded nor welded). This means that the assembly of the ship can be done quite quickly, but a lot of workers may be required because of the parallel working.

Blocks are considered to be ring blocks for the used ships. Ring blocks do not have to be stacked any more, except for the accomodation. However, the accomodation is generally the last block that is assembled to the ship. The welding of these ring blocks is two-dimensional (height and width, or width and length for accomodation blocks), while the assembly of sections has three dimensions. Therefore the two are calculated separately.

The workers involved in this process are ship erecters and welders. Data show that ship erecters require 55% of the hours and welders 45%. Currenly at Damex for ship erection by using sections or blocks four of each are required.

Hot/cold outfitting: For both hot and cold outfitting the index hours/component weight can be used [5], but in this research the index hours/item is used. This is done because of the lack of data and the variance in weights for different ships. For example the Spa4207 is lightly built, including its piping; while the Sla5612 is heavily built, including its piping (Spa4207 piping is optimized for weight, while Sla5612 piping may have some margin of safety). Therefore the fitting of a pipe with the same measurements take roughly the same time, but its weigh varies.

The index hours/item index is not ideal. A big component takes much longer to install than a small one. Therefore in appendices D and E a division is made between large and small components.

The phase in which the components are fitted also influences the time that is required, as is explained in sections 5.4, 5.5 and 5.6. The differences for small ships are established as following:

Table 16. Man-hours and throughput time percentages of outfitting per intermediate product

Process	Man-hour %	Throughput time %
Section pre-outfit	100%	100%
Block oufit	200%	150%
Ship dry outfit	400%	250%
Ship wet oufit	500%	250%

Per ship the time can also vary. The Spa4207 is constructed much more compact than the Sla5612 and Stu2208 for operational reasons. This means that the outfit has to be fitted in much narrower space during ship outfitting than the other two. According to R. Kentie this takes 30% more time than the other two.

Painting: For painting the index hours/painted area [5] can be used, but for this research the index hours/(equivalent) weight/layer is used. This is done because the specific areas are not known, and the weight of the section or ship, compensated for steel thickness, gives a good approximation of this area. The painting is split up in layers because the paint system requires four layers of paint, in which the first three can be applied after the hot works in section building.

By using these estimators, the required time can be calculated by simply put in the required number of ships and its ship parts to be built per year. Man-hours are determined according to the throughput time (or a percentage) per part, number of parts per year and number of required workers per part

6.1.2 Estimators of required production cranes and transport means

Cranes are used for both production and transport. Other transport means are forklifts and a section transporter. In theory each production and transport mean is fully available during production hours, which is a theoretical 2200 hours per year.

In reality this number is not always reached. Damex' heaviest crane is an old 100 tons which worked in 2011 for only 650 hours. The numbers of the other cranes and/or transport means are unknown, but observations show that these resources are regularly broken. The following production cranes and transport means were available or broken during my stay at Damex:

Table 17. Current crane and transport capacity

Production crane or transport machine	Lift capacity	Functioning
Heavy crawler crane (old); new one has been delivered recently	100 tons	Working (new), 650 hours (old)
Medium mobile crane	50 tons	Working
Light mobile crane	12 tons	Temporary broken
Tower crane	10 tons	Working
Tower crane (mainly for ship repair)	10 tons	Temporary broken
Small steel part processing shed crane	5 tons	Working
Heavy forklift	5 tons	Working
Heavy forklift	5 tons	Temporary broken

For this resource calculation the labour standards are engineered. This is because there is no historical data available about all resources. Process times are estimated by using expert opinion and non-process times estimated by using literature and expert opinion. The number of crane moves that are made per sub-process per ship is stated in section 5.8.

For casco production the following crane hours are used.

Table 18. Specific casco building crane move durations

Process casco building	Crane use time estimation	Remarks
Position plate	15 min	Vertical lifting, open top
Position profile	5 min	Vertical lifting, open top
Position sub panel	30 min	Vertical lifting, open top
Position main panel	30 min	Vertical lifting, open top
Turn plate-field	2 hours	
Position section/block	4 hours	Vertical lifting, open top
Turn section	4 hours	

For outfitting the following crane hours are used.

Table 19. Specific outfitting crane move durations

Process outfitting	Crane use time estimation	Remarks
Position light (<1t) outfit item	15 mins	Vertical lifting, open top
Position heavy (>1t) outfit item	4 hours	Vertical lifting, open top

These numbers are estimated process times. The non-process times are not available. The current lack of lifting and transport capacity creates long waiting times for Damex. When performing an unpredictible operation, like a transport move, and when machine utilization is very high, the waiting time becomes very long [2]. More of this is explained in chapter 7.

The lack of historical data causes that process times are engineered by using expert numbers, non-process times are engineered by using literature. This means that the generated resource number is not too reliable. Unfortunately the utilization per crane is not known precisely. The total number of cranes is known, as is the number of crane and transport drivers. Required crane moves are derived from the process model and product data, and crane move data is estimated by consulting with experts. Better quality data is required to make better predictions regarding these crane move times.

6.1.3 Estimation of area

Area is determined according to throughput time per part, the number of parts per year and required area per part. However, the average resources do not take into account extreme requirements. Extreme resource requirements and the tackling of them are listed below.

Dedicated production area is the least flexible. The production are must be able to facilitate the biggest product that is to be produced per sub-process for all ships in the portfolio. However when more area is required to produce products parrallely, problems arise when using mere averages. Producing only the biggest parts parrallely is not feasible. For example the biggest section of a SLa5612 is the aft peak section. During section building it is unfeasible to build only aft peak sections, since there is only one required per ship.

However concerning main panels this is not certain. Therefore the area distribution is set out. The average main panel area is roughly 32 m2. The distibution is not entirely normal, as can be seen in the following graph.

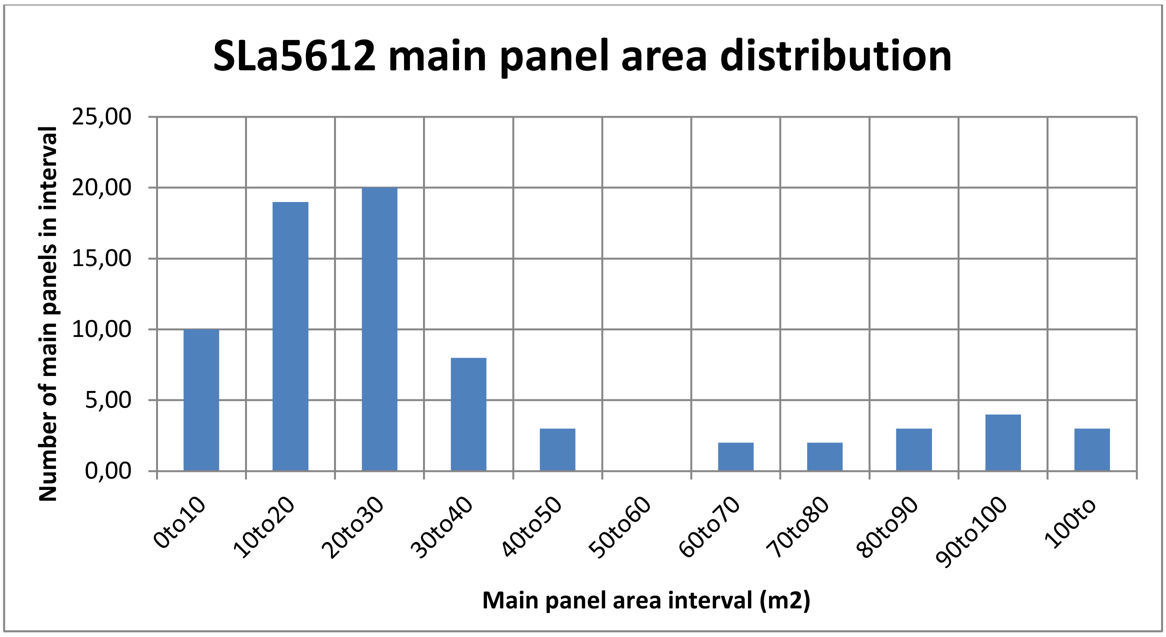

Figure 47. Stan Lander 5612 main panel area distribution

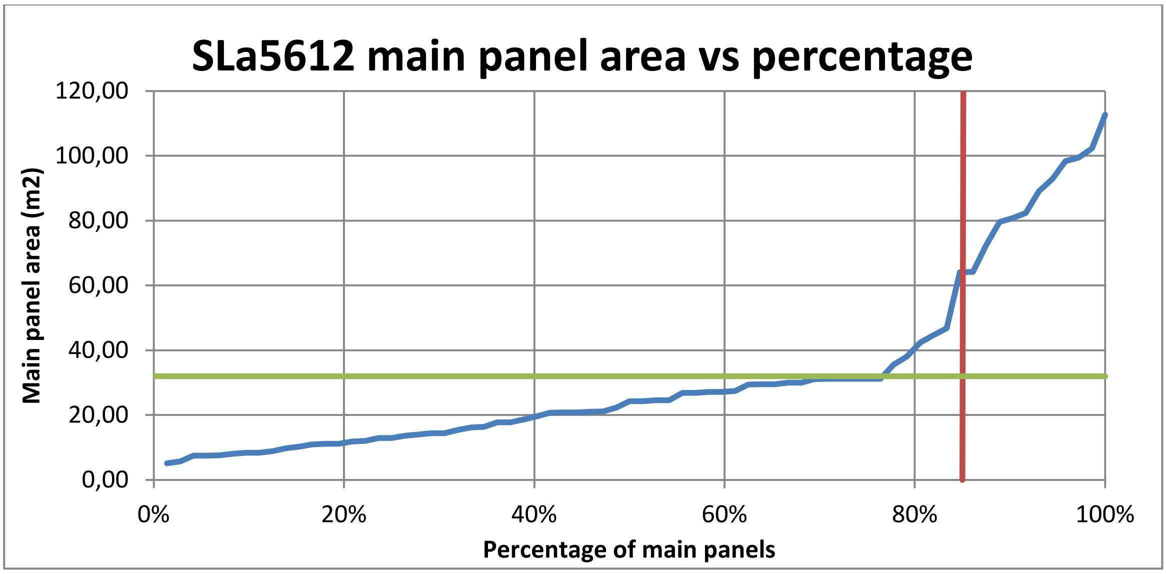

Figure 48. Stan Lander 5612 main panel area analysis

Now the main panel area is set out against the percentage of main panels of the Sla5612. The average main panel area of 32 m2 is shown by the green line. The average plus one standard deviation comprises 84% of the main panels, which is shown by the red line.

Calculating by this number as the used area, including the previously mentioned in- and output buffers, results in an area in which at least 2 of the biggest main panels can be manufactured, or 6 average main panels. Therefore the average are plus one standard deviation is used to cover the peaks when production is to be done parralelly.

6.2 Ship assembly data

The estimators mentioned in section 6.1 require product data and production data.

6.2.1 Casco data

For the average casco parts per ship type the average (local) throughput times are determined by using the estimators mentioned above. Data is estimated with help from expert experience numbers at DSGo, Damex, DSNS and Bergej Shipyard; and Damex registered reference hours.

Panel (2D steel) assembly: This type of steel production hours is more or less independent of steel weight [14]. The hours are determined more by the area of the 2D construction than the weight. This is dependent on the parts per area ratio, since more parts per area mean more adjusting, tack welding and welding meters; which means more work and more time.

Table 20. Panel production data

[SLa5612; STu2208; SPa4207]	Output/year required	Parts/m2	Hours/m2	Workers	% Steel worker hours	% Welder hours	Prod. crane moves
Sub panels	[764; 1455; 900]	[1,36; 2,21; 2,14]	[0,47; 0,77; 0,74]	1	55	45	[1578; 2690; 1540]
Main panels	[148; 120; 120]	[0,63; 1,10; 1,10]	[1,31; 2,28; 2,28]	2	55	45	[3258; 2650; 2760]
Rigid main panels	[66; 50; 54]	[0,28; 0,59; 0,58]	[1,31; 2,77; 2,70]	2	55	45	[588; 1085; 654]

Section, block and ship (3D steel) assembly: This type of steel production hours is dependent on steel weight, corrected for parts per ton and steel thickness. The parts per ton ratio is an estimator of the adjusting, tack welding and welding meters of the 3D construction. A plate thickness correction is also required when using the hours per ton ratio.

Table 21. Section, block and ship production data

[SLa5612; STu2208; SPa4207]	Output/year required	Parts/ton	Hours/ton	Workers	% Steel worker hours	% Welder hours	Prod. crane moves
Sections	[58; 45; 24]	[6,17; 11,54; 12,54]	[23,35; 39,70; 43,14]	2	55	45	[1424; 745; 178]
Blocks	n/a	n/a	n/a	2	55	45	0
Ship (sections)	[58; 45; 24]	[0,07; 0,09; 0,07]	[9,74; 11,67; 9]	4	55	45	0
Ship	n/a	n/a	n/a	4	55	45	0

(blocks)							

6.2.2 Outfit

Outfitting is done in several phases of the production process. Each phase and even each ship has its own conditions. The phase distribution of man-hours and time of chapter 6 is used. The amount of parts per phase is dependent on the chosen advancement of the interim products. The table below shows the used distribution of the current situation.

The SPa4207 spaces are narrower and have less accessibility than the other two ships and takes 30% more time per part during the dry and wet ship outfitting phases.

Table 22. Outfit production data

[SLa5612; STu2208; SPa4207]	Output/year required	Hours/item	Workers	Prod. crane moves
Hot outfit (sections)	[2121; 2476; 2318] parts	[2,8; 3,64; 3,13]	2	[1424; 1747; 1193]
Hot outfit (slipway ship)	[1699; 1356; 1483]	[5,1; 8,5; 7,8]	3	[1030; 1317; 923]
Hot outfit (quay ship)	[24; 13; 15]	[6; 3; 3,9]	4	[33; 44; 23]
Cold outfit (section/blocks)	n/a	n/a	2	n/a
Cold outfit (slipway ship)	[2684; 2136; 3889]	[1,87; 2,8; 2,5]	3	In hot outfit moves
Cold outfit (quay ship)	[1685; 1094; 2072]	[2,35; 2,93; 2,96]	4	In hot outfit moves

6.2.3 Paint

Painting the main surfaces can be done after the hot works in section building, or when the ship is erected at the slipway. The surface is to be cleaned and blasted, and four layers of paint have to be applied. Blasting and painting 3 sub layers can be done after section building. The final layer is to be applied on the slipway after completion.

Table 23. Conservation data

[SLa5612; STu2208; SPa4207]	Hours/layer section	Hours/layer ship	Workers	(equivalent) Tons/section
Paint	[44; 31; 74]	[1600; 460; 1000]	2; 6	[15,3; 10,8; 25,8]

6.3 Validity of data

Production data gathered at Damex is based on experience of the local Dutch supervisors, Cuban managers and foremen. Registered historical Damex data has been aqcuired. Incomplete Cuban data is completed by estimations of Dutch experts at DSGo.

Production data of more advanced shipyards is used to estimate possible future production data. This is data from the former Van der Giessen- de Noord shipyard, Damen Naval Shipbuilding in Vlissingen, the Dutch reference shipyard man-hours (DSGo experience of various Dutch yards) from the IDK data and the former Bergej Shipyard in Serbia.

Current production times are based on experiences of F. Brossard, A. Guzman (Damex), R. Kentie (Technical Support, Damex); J.B.B. Teuben (DSGo, former Van der Giessen – De Noord); DSNS casco planning guidelines; DSGo IDK references; former Bergej Shipyard data.

Theoretical values from machines for engineering data are derived from Hengst [3], DSKo welding data; Moggy Welding Tractor product information.

6.3.1 Validity of calculating with averages

The main problem by only calculating in excel rather than simulation, is the extreme values of required resources are averaged and no longer visible in the calculation model. In reality these extremes do exist and therefore have to be taken into account.

Worker occupation: In this research peaks in worker occupation are not taken into account, since they are not part of an investment plan. The overall number of man-hours is taken into account, since they comprise a substatial amount of the costs. They can be calculated by summing the averages.

Area occupation: As stated in 5.7 not the average area is used, but the average plus one standard deviation. This, and some in- and output buffers make sure there is sufficient area for production.

Machine utilization: The desired theoretical machine utilization depends on the variability of the process, desired waiting time and the desired investment. In this research light transport and production crane moves are considered as highly variable, and require a theoretical utilization of 50%. Heavy transport moves are considered medium variable and require a theoretical utilization of 70%. Pre-process machine processes are considered low in variablility and can have a theoretical utilization of 95%.

7 PRODUCTIVITY IMPROVING METHODS FOR SHIP ASSEMBLY

There are many ways to build a complex product like a ship. As can be seen in chapter 5 the ship assembly process is divided in several sub processes. Each of these processes can be done in several ways, which requires different resources. In chapter 2 some methods of improving productivity are introduced. These methods are elaborated in this chapter. In this chapter the following secondary research questions are answered:

- **How can Damex' sub-processes be more productive?**
- **How are the shipyard sub-processes' workloads and resources arranged at reference shipyards?**

The used method in this chapter is to look for improvement of the current way of working, which is set as building scenario 0. This inherently means that all less productive methods are not looked at. All processes require production machines and cranes; workers; transport methods and a production location. Because of the current crane and forklift scarcity at Damex, these production and transport means are considered fully utilized by Dutch and Cuban Damex managers.

Shipyard productivity can be increased by mechanization and automation of processes [3, 4, 15]. Another way of increasing efficiency per ship is maximizing the learning effect by series fabrication [3, 9, 11], changing interim products or building strategy [3, 4, 5, 21, 24] and changing the organization by reducing waste [2, 12, 19, 24, 25]. Methods are qualitatively assessed in this chapter for feasibility at Damex.

Reference shipyard data and its methods are used to determine the effects of the proposed productivity improving methods. Production scenarios are developed, which are based on one specific set of measures.

7.1 Ship assembly overall organization improvement

Currently the ship assembly layout at Damex is not following the process model as presented in chapter 5. In literature there are several process layouts for different products. For this research only the fixed position- and process layout [2] are taken into account. Slack gives the following layouts:

- Fixed position layout: Product is generally too big to move, or fixed. Devoted resources are required.
- Process layout: Process equipment is grouped together per function. Different specialized departments can appear this way.

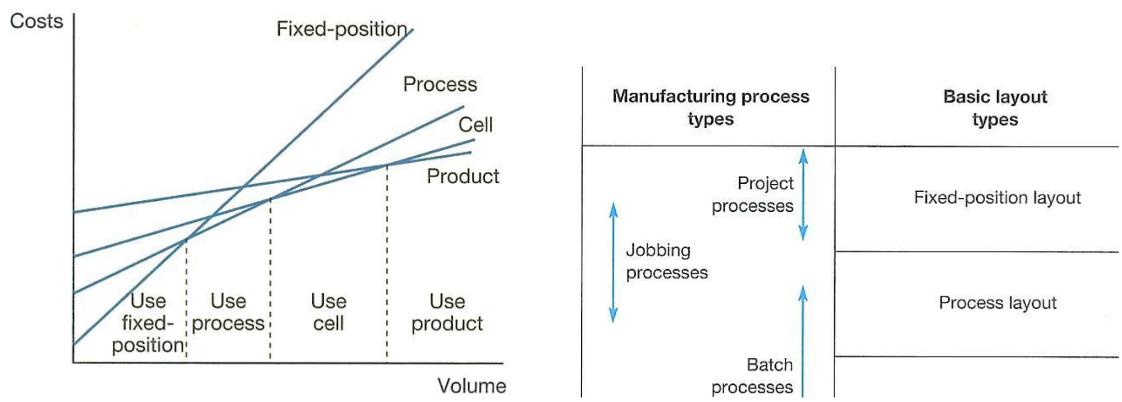

Figure 49. Costs, layout and process type relations (Slack [2])

Figure 49 gives the relations between costs, process types and layouts. In this research, for ship assembly, all processes before the slipway and outfitting quay are seen as jobbing processes. From the slipway, ship assembly processes are considered project processes, because of the low production volume and devoted resources. As can be seen in the shown graphs [..], they ought to be arranged in a process layout to reduce costs.

7.2 Mechanization and automation

Mechanization and automation can increase the speed of certain activities, which means less throughput time. Also it can reduce the amount of workers that is required for the same process. This can reduce throughput time and/or man-hours per activity, which therefore will be more efficient [3] compared to the previous method.

Another advantage of mechanization and/or automation is the built-in quality in the process. This reduces rework.

Welding mechanization: Currently welding is done manually (electrode, CO_2), except for the SAW welding during panel building. A possibility is to do other welding mechanized (SAW and fillet weld tractors). At some large shipyards it is done fully automated by using weld robots. Welding mechanization is not necessarily faster, but more reliable than manual welding. This generally means less rework waste. Only when using dual- or multiple weld guns, welding time can be decreased. Dual weld guns roughly halve the weld time of profiles compared to one manual CO_2 welder, or halve the man-hours compared to two CO_2 welders.

Panel building mechanization: On a panel line positioning can be mechanized. However, a panel line is very expensive (in the millions of Euros, indication is €3 000 000,-) and the main panel production amount is too small to earn this back.

7.3 Maximizing of learning effects

Repetition and experience breed competence. This is called the learning effect. To determine the gain in efficiency by performing repetitive work, the learning curve for shipbuilding is investigated. The OECD CGT system report (2007) [9] gives the following learning curve for shipbuilding:

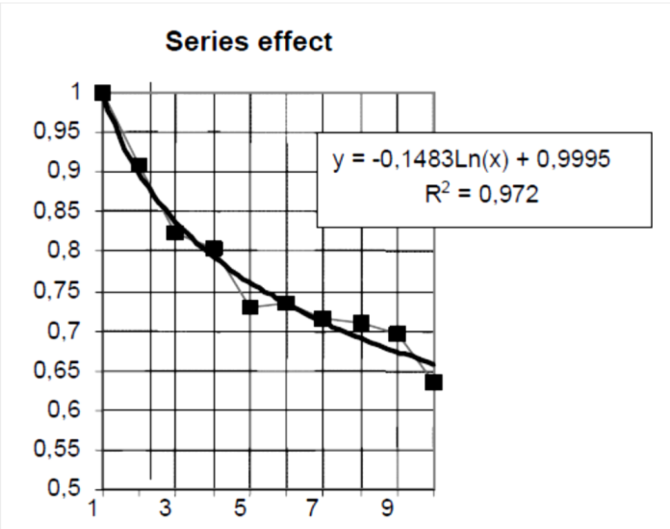

Figure 50. Learning curve of ship series (OECD [9])

This shipbuilding learning curve shows that building the 9th of a series takes roughly 70% of the effort of the first of that series, which means they work 30% more efficient.

The shipbuilding learning curve is determined concerning the building of a whole ship. In other industries there are other steeper learning curves. For example Gulfstream airplane parts manufacturing has the following learning curve:

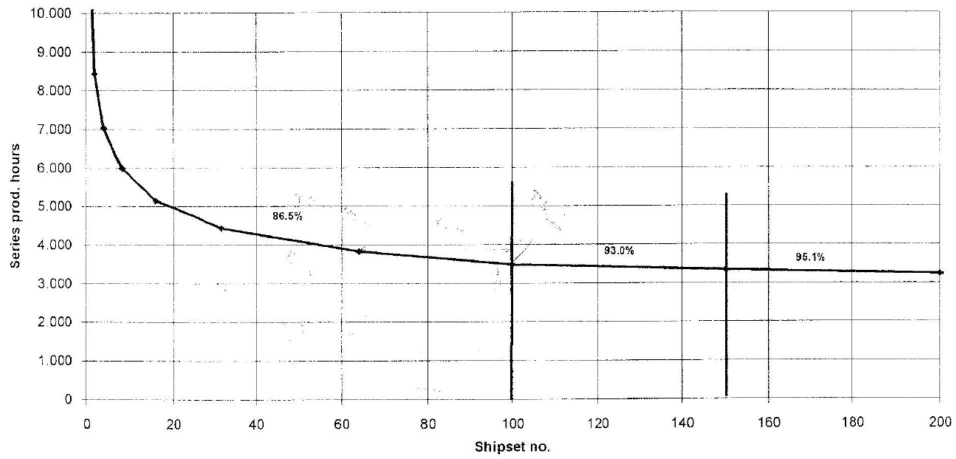

Figure 51. Gulfstream parts manufacturing learning curve (R. van der Reijden)

However, this experience is significantly (70%) reduced in more than 2 months [Globerson [10]]. This can be seen in figure 52.

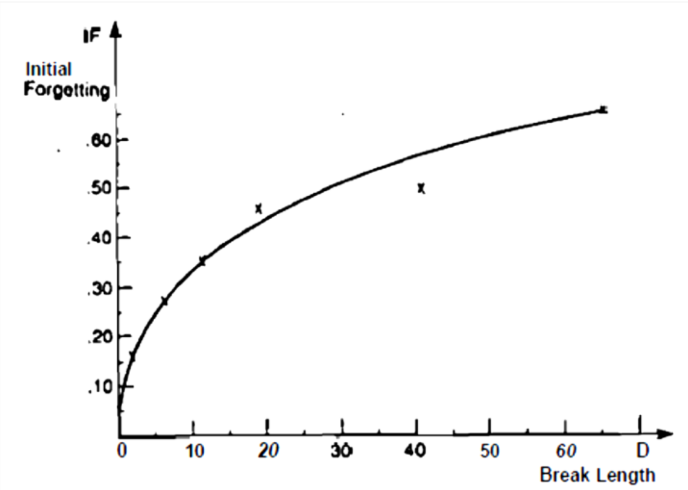

Figure 52. Forgetting curve (Globerson [10])

This means that when performing certain non-repetitive activities that take longer than 2 months, productivity gains by learning is greatly reduced.

Where the workers of Damex are located on the chart is not known, therefore they are considered experienced. Workers at Damex are specialized to a certain level, since specialization is certainly observed (steel workers, welders, pipe fitters, electricians etc.). This means that they are doing repetitive work to an extent. It is not clear how much productivity they gain when doing more repetitive work, since the place on the line in the graph is unknown.

7.4 Changing advancement of interim products or building strategy

Building strategy means the used method of dividing the ship in intermediate products for easier building the complex ship. Building methods can greatly affect the throughput time of a (part of a) ship. The current section and construction plans are used. But there are some other variations possible. According to Hengst [3] shipbuilding is an assembly process with an increasing complexity in the progress of the process. Therefore prefabricated interim products should be as advanced as reasonably possible.

7.4.1 Increase advancement of sections

Sections are interim products for producing blocks and/or ships. Since WW2 sections are used for producing ships [4; 15]. At Damex this is the same. During section building a large amount of the hot outfit can be mounted in the sections. Also the section can be painted. When the hot works and paint works are finished, cold outfit can be mounted in the section.

7.4.2 Increase advancement of blocks

Blocks are interim products for producing ships. Blocks can be constructed from sections at a dedicated location to reduce the time that is required to erect the ship at the slipway. After building blocks from sections that are fitted with hot outfit and painted, cold outfit can be mounted in the block.

Outfit can be mounted in less awkward positions during section building or after block building. In this way time is reduced to mount outfit and to paint at the slipway and outfitting quay. Also because of the less awkward positions, opened platforms and less walking time the processes are done more efficiently. How much this is exactly is shown in section 6.1.

7.5 Changing organization by elimination of waste

The main way of gaining productivity is by improving the organization of all resources and material [3]. This can be done by the elimination of waste, or Lean manufacturing. There are many (commercial) Lean Manufacturing methods like, Toyota Production System, Lean Six Sigma etc. This research is done by following the waste elimination rules stated in Slack [2]:

Forms of waste:

- Over production: Producing something that is not sold costs money.
- Waiting time: Idle workers and unsold products cost space and money
- Transport: Transport costs space, time, energy, transport machines and workers, and thus money
- Over-processing (non value adding processes): Processing costs money, if no value is added this process only costs money.
- Inventory: Costs space, and thus money
- Motion: Costs time and energy of transport machines and workers, and thus money
- Defectives: Defectives cannot be sold, have to be repaired and therefore costs money

7.5.1 Elimination of over production

Currently at Damex there is no such thing as over production, since ships are not built for stock for Damex.

7.5.2 Elimination of waiting time

Due to the lack of transport or production machines, there is a significant amount of waiting time. There is also a lot of waiting time for functioning production tools and weather delay. When material is waiting, no value is added and therefore no money is earned.

Waiting due to machine occupation

Waiting time occurs when a production machine or crane is occupied. However, utilizing capital production assets is preferred since it reduces required investment, and therefore the depreciation costs. Waiting time increases exponentially when machine utilization (occupation) increases. A 100% utilization theoretically means infinite waiting.

Slack gives the following relation between waiting time and capital utilization in figure 53.

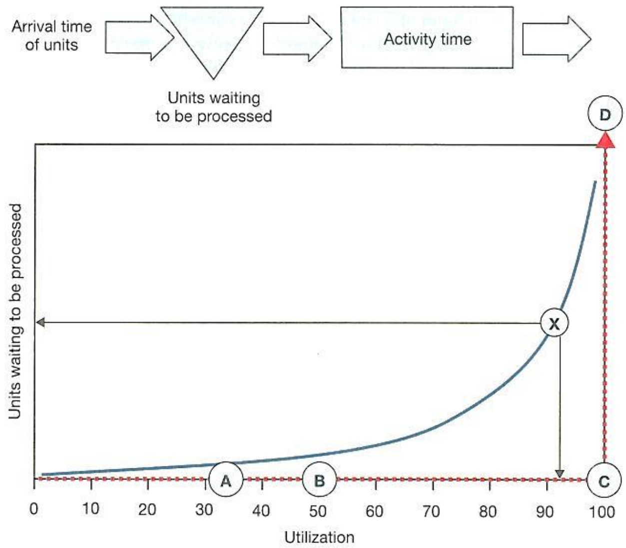

Figure 53. Machine utilization and waiting time relation (Slack [2])

The relation between utilization and waiting times can be improved when the cycle time, or takt time, is more balanced. Slack gives the following figures regarding waiting times:

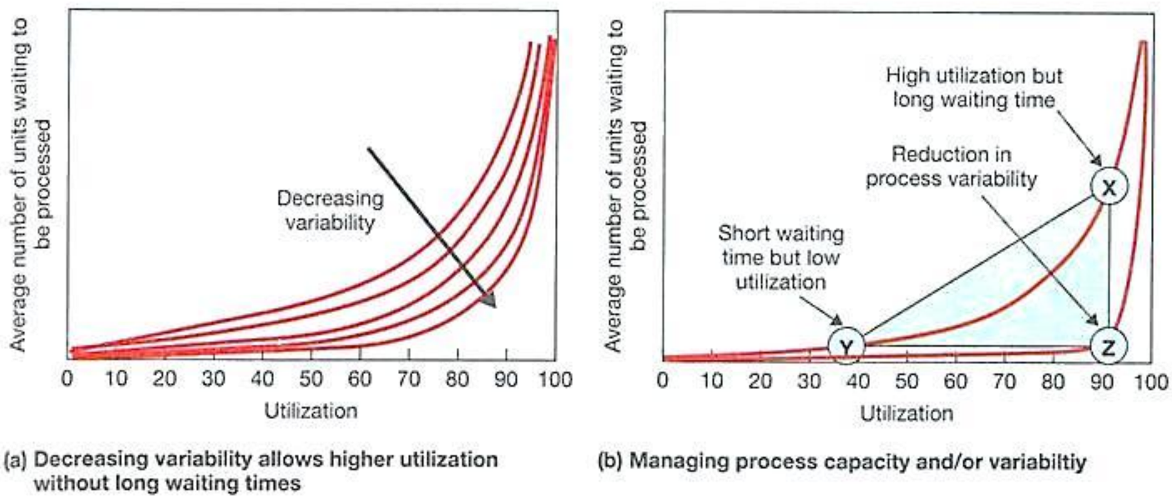

Figure 54. Machine utilization, waiting time and product variability relation (Slack [2])

Unfortunately the waiting time relation is shown without an absolute Y-axis in the graph. Therefore only a relative number can be taken from this. The safest estimation of this relation is at the highest variability level. At this level a 50% utilization results in a reduction of waiting time of 80%, compared to a utilization of 95%.

When variability in products is decreased, the cycle times can be more balanced and capital utilization can be increased. However, this is not in the scope of this research. Current design and engineering information is used.

A 95% utilization grade gives at least 5 times more waiting time than 50% utilization; with the exception of course when cycle times are well balanced. This can be applied to transport machines. Transport machines generally have no balanced cycle time, with some exceptions. The cycle times of steel part processing are considered to be more balanced than further in the process. For production cranes however, there is hardly any balance, with the exception of a panel lane. This means that 50% utilization reduces waiting time by 80% compared to 95% utilization.

Average cycle times or 'takt times' can be calculated by using Little's Law for intermediate products [2; 5].

How much exactly the waiting time is reduced when variability is decreased, is not quantitatively known. Therefore the previously mentioned conservative estimation is used, in combination with data about reference shipyards.

Minimum waiting and reasonable utilization is estimated at 50% theoretical utilization, which means that the theoretical crane hours must be doubled to determine the optimal required cranes.

Heavy transports are generally planned by the management, and therefore can be utilized more, because the variability is managed (see figure 54). A 70% theoretical utilization is estimated to be sufficient for this type of machine.

Due to the machine shortages at Cuba the occupation of transport and production machines is considered 95%.

<u>Waiting due to weather delays</u>

Working outside is cheap, but an excess of sun/heat and rain may cause disruptions in production.

Production can take place outside under a temporary movable shelter (figure 55), under a movable hall on rails (figure 55) or in a permanent building.

Working under the current temporary movable shelter mitigates the sun/heat factor a bit, but rain still causes disruptions. Also a crane is required to move the shelter, which results in more crane use. When rails are present, gantry cranes can be used for transport and production purposes. Gantry cranes can be remotely operated by workers. This means that no crane operators are necessary for the particular crane. Again, when no rails are available, field machinery is required. This solution by using field machinery is currently used at Damex.

A movable roof on rails mitigates the sun and crane hour problems. Moving the roof can be done manually. On a rail track next to the shed a gantry crane can move over it, requiring no crane operator. When no rails are available, field machinery is required. The roof has to be moved aside when lifting by crane is required. Rain may still cause problems when it is in combination with wind.

Another possibility is the permanent fully covered building. Transport and production overhead or semi-gantry cranes, their tracks and foundations are to be included in this facility. This is the most expensive option, but sun, rain and crane problems are all solved, which means the least waiting time. Furthermore, remotely controlled factory cranes do not require crane operators anymore.

Figure 55. Damex movable shelters and Wilson sons movable halls

A movable roof on rails saves the movement of shelters before positioning items, but rain downtime is still a problem. When it is raining, welding is not possible since it is not safe. Also it is impossible to paint outside during rain. Furthermore it is very uncomfortable to work outside during rain. This means that during rain no outside work can be done. This is considered waiting time.

Local weather data is used to approximate the waiting time for better weather.

On average there are 9,75 days of rain per month and 30,5 days per month. This means there is rain in 32% of the days in Santiago de Cuba. However, it doesn't rain the whole day. The average hours of daylight is 12,1 and the average hours without sun (except during night of course) is 5,5. This means that approx. 46% of the day is can rain for 32% of the year, which is 15% of the year. So during 15% of the year it is impossible to produce anything outside. [28]

Another weather phenomenon in Santiago de Cuba is the heat. When working on board of a ship in the full sun at 30 degrees Celsius, work does not go that fast. However how much time this saves is not clear. More data is required to quantify this.

Production under a roof has some direct and indirect advantages. Direct advantages are weather independency and the elimination of moving the shelters by crane. A conventional production hall saves the same crane moves, and rain downtime. But it limits the use of field equipment, since they take too much space. This means extra investments for indoor factory crane capacity have to be made for this option.

Waiting due to breakdowns

Routine productive maintenance focused on prevention of break down. Currently at Damex preventive maintenance is rare. The maintenance and repair department main occupation is repairing broken equipment. Production is working with the equipment until it is broken. This also causes delays.

7.5.3 Elimination of transport

The transport distance and organization of certain intermediate products can be improved to minimize required transport machines.

Lay-out for smooth flow:

- Smooth flow of materials, information and resources.
- Place common workstations close and in sight to each other for transparency.
- Create flow by balancing and synchronizing capacity, reducing distances between following processes and obvious material routes.

Currently Damex production layout is arranged around the slipway. This is not a smooth flow of materials, information and resources. Distances between following processes are sometimes small and sometimes big. This can be improved by changing the layout of the shipyard.

7.5.4 Elimination of over-processing

Over-processing at Damex is mainly the rework. When something is produced that is not in accordance to the standards, or when it is screwed up by a following process, rework is necessary. For example when a surface is painted, someone is welding something on the surface. The paint is damaged and has to be grinded off and repainted. This is more processing than welding and painting after that. However, this cannot be mitigated by investments. Management, a different reward system and training is required to counter this problem.

Another form of over-processing is welding plates to eachother that do not necessarily have to be welded. Using plates of 6 or 12m long depends on the cutting size capacity of the plat cutting and marking machine and the available transport means. Bigger plates usually result in fewer parts per ship, which results in less assembly and welding hours.

7.5.5 Elimination of inventory

At Damex there is a large amount of inventory, however this is not seen as a big problem currently, since a buffer generally reduces the waiting time for input materials. Ruffa [30], in the figure 56 states that inventory has to be controlled first in order to gain control of the production process. Since Damex does not control its supply chain (controlled by DSGo), considerable initial buffers must be maintained.

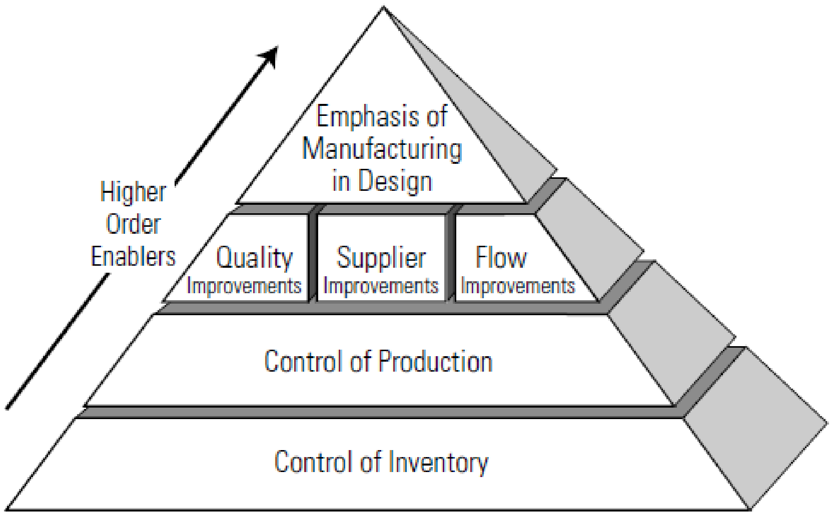

Figure 56. Lean manufacturing order of implementation (Ruffa [30])

First DSGo has to control its own supply chain, before this waste type is further tackled. Also the arrival and stocking of materials is not in the scope of this research.

During ship assembly several local buffers are held in order to reduce waiting for materials. They are held before and after the level 1 sub-processes, which is shown in the level 2 processes in their specific appendices.

7.5.6 Elimination of motion

There is too much motion of resources observed at Damex, because this shipyard has a large area and there is a shortage of transport machines. This causes transport machines to move all over the shipyard. This is to be taken into account in the new layout design. Repositioning the intermediate product to another spot is seen as transport. Motion of personnel to the toilet or cafeteria is not taken into account, since Astor (see chapter 1) is responsible for that and the scope is ship production.

7.5.7 Elimination of defectives

There are examples of defective intermediate products, which have required rework. The reasons for defectives are lack of measurement control. This is partly due to lacking tools. But the main reason is the Cuban system of rewarding employees. Cuban workers generally don't feel responsible for the quality of the product. When a bonus is given for each working product, this can be improved. However, since Cuba is a communistic country, this is not possible, since this would create inequality.

7.6 The reference shipyard

The man-hour budget estimation at DSGo (or IDK) is based on the man-hours of an ideal Dutch shipyard. Since DSGo does not build cascos themselves, it is not sure which shipyard this is. This shipyard is the ideal point of reference for comparison of foreign shipyards that also build DSGo ships. These (man-hour only) references are considered to be ideal, except potential section/block outfitting efficiency gains, since DSGo ships have no tradition of being section/block outfitted.

This scenario is considered to be Lean, which means that there are minimum waiting, rework and transport hours.

7.6.1 Ideal 'Dutch' reference shipyard description

In the IDK man-hour estimation there are Dutch reference man-hours. In this research these Dutch man-hours are considered to be ideal. This is not necessarily 100% true, but it is the best approximation that is available for this research.

Therefore some assumptions are made. The ' Dutch' reference shipyard is:

- Fully covered production
- Has mechanized welding
- Production is properly located, organized and equipped
- Uses 12m long plates
- Has the current Damex amount of pre-outfitting, since Damen has no block outfitting tradition (except for the bigger ships of DSNS and DSGa)

Workers are rewarded in a western fashion, which means for merit. This means that workers are encouraged and rewarded to build products in one time right, which leads to less rework than at Damex. Also power, materials supply and public transport are considered reliable.

For all three products the comparison in man-hours is as following.

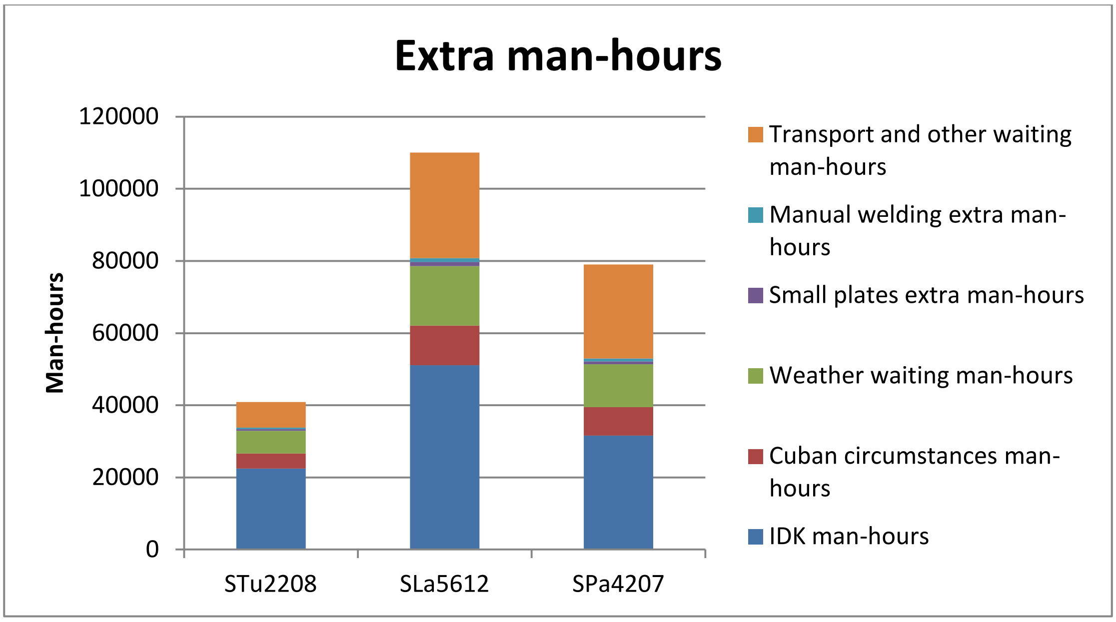

Figure 57. Extra man-hours per ship compared to reference shipyard

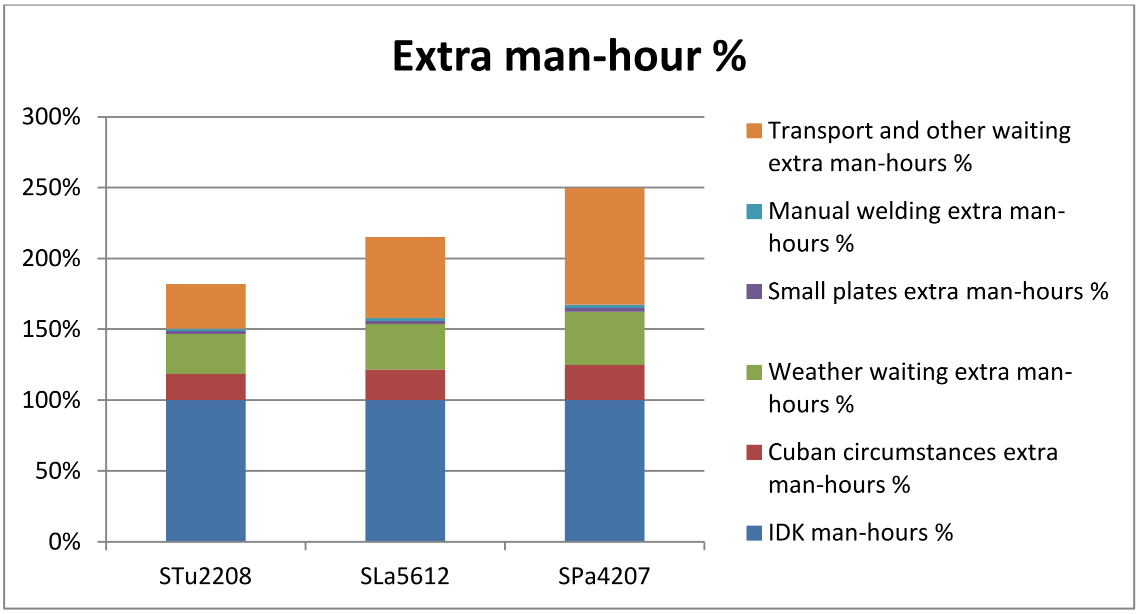

Figure 58. Extra man-hours percentage per ship compared to reference shipyard

In this fashion the amount of waiting is determined for cranes, forklifts or other materials and tools. For the investment only the cranes and building are taken into account, since welding equipment is considered as tools.

As pointed out in 6.2.2 the historical data corresponds with the availability of resources. During the production of the SLa5612 several cranes were broken, which means they have relatively more waiting time for transport etc. than the STu2208. Also the available historical data of the SLa5612 is from the first in a series of 4. For the SPa4207 the casco data is unreliable, as pointed out in chapter 3. Also the production data is unreliable, since there is no historic reference data, as pointed out in chapter 6.

For comparison of the old situation with the new one, to make a conservative estimation, every machine is considered to be functional, which means the STu2208 waiting scenario is assumed.

7.7 Feasible production method scenarios for calculation

Now every possible way and the current way of performing the required processes are known and the worse than current- and unfeasible options are eliminated qualitatively, the feasible production scenarios are developed. The basis of the scenarios is to keep the variables as low as possible. Therefore only one (or more when the scenario is based on the previous) type of improvement is chosen per scenario. The improvement is generally applied over all the sub processes.

7.7.1 Current practice: production scenario 0

Currently at Damex the plate and profile prefabrication processes are partly (curved, very thick and thin plates; most curved profiles) outsourced. Local plate fabrication is done by unreliable machines under a permanent roof. Profiles are prefabricated manually. Several profiles are prefabricated by section builders. Transport is done by a small crane and a field forklift. Production takes place under a temporary movable shelter.

Panels and sections are built under a temporary movable shelter by section builders and welders. They are generally welded manually, but panel butt welding is mechanized. Production crane capacity is provided by mobile field cranes and a tower crane. Transport is provided by field forklifts and mobile field cranes. Both are considered fully occupied, which is 95%.

Sections are pre-outfitted under a temporary movable shelter by specific fitters and welders. Section pre-outfitting is done manually. Production crane capacity is provided by mobile field cranes and a tower crane. Transport is provided by field forklifts and mobile field cranes.

Blocks are neither built nor outfitted.

Sections are erected to ships at the outside slipway under several temporary movable shelters. The assembly welding is done manually by using CO2 welding with ceramic weld backing. Production crane capacity and transport is provided by mobile field cranes.

At the slipway the ship is outfitted during the ship erection process. When the structural hull works are finished, the hull is wholly painted and launched. Production crane capacity is provided by mobile field and the tower crane. Transport is provided by heavy forklifts and a tower crane.

At the outfitting quay the ship's outfit is finished. Trials and commissioning is done locally. Production crane capacity is provided by an industrial tower crane. Transport is provided by field forklifts and the tower crane.

Observations at Damex show that there is a lack of (working) transport and production machines and facilities. This means that the waiting for these machines costs a lot of time [2]. Also measurement accuracy control is lacking, which means substantial rework.

7.7.2 Fully roofed, weather independent production scenario

In this scenario the production takes place in a fully covered production location. Workers are protected from rain, wind and sun. Current field equipment cannot move inside the halls, so investments have to be done to buy new equipment.

When the covered production location is properly located, organized and equipped, a better material flow and sufficient facilities result in reduced waiting [2, 19, 24, 25]. The current layout and material flow at Damex is not considered optimal. Parts are transported around at the shipyard by using field equipment. More transport distance requires more transport time. Field equipment is used because of the partly unpaved terrain, and because of the non-continuous process flow. However field equipment requires a lot of space to move, and waiting for transport resources because of the long distances is not considered as value adding.

However, to keep the variability low, the scenario is only the fully covered production and no production alignment or more machines. This scenario is covering the weather independence only. It is unrealistic in real life, but good for comparison.

Remark: Since the ship assembly of Damex is currently outside, transport and production is currently done by field machinery. Field machines are robust machines on wheels or tracks, and can move very well outside. Field machinery is versatile, but requires a lot of space to move. But when working inside a factory hall, field equipment cannot operate there and factory equipment is required

Remark: As stated in chapters 1 and 5, currently a new covered slipway is being built at Damex. This means that no investment is required for this, and that the ship erection and ship outfitting at the slipway are performed covered in the as-is scenario.

7.7.3 Minimum waiting for production and transport cranes and forklifts scenario

For machines and facilities with unbalanced cycle times and 95% utilization, considerable waiting time is inevitable. For the many processes that have unbalanced cycle times this is not desirable. Plate and profile steel part processing are considered balanced (see 6.1 and appendix I). Moves of the heavy crane are considered more or less balanced (see 6.1).

This means that light crane theoretical utilization is to be no more than 50%. Utilization of lifting machines and facilities are currently considered to be 95%, which means fully utilized.

As mentioned in chapter 5, there is no historical data about the use of cranes at Damex. However considering the production time and man-hours there is historical data available regarding Dutch reference shipyards at DSGo for the built products. However, the production methods of this reference shipyard are only known quantitatively and are described in 6.3.

The reduction of man-hours for waiting for cranes and other material is calculated by taking the difference between the ideal ‘Dutch’ reference shipyard data and the current Damex data, minus the known quantifiable measures shown in 6.3.

The minimum waiting scenario consists of the current production layout, except that there are sufficient production and transport cranes and forklifts, other equipment and production organization. Organization however does not require an investment of DSGo, and is therefore not further elaborated.

For this scenario it is important to consider that the current available (and functioning) cranes and other transport means must travel a longer distance than in this scenario. Assumed is that picking up and unloading cost 1/3 of the time each. Transport costs the other 1/3. The transport distance is assumed half of the current one. Therefore the total transport time is 1/6 lower than the current one. This is an assumption and should be further researched.

7.7.4 Mechanized welding scenario

Welding robots are expensive machines that need expensive facilities inside a building. Welding robots are not necessarily welding faster than manual welders or welding tractors. Welding robots reduce the man-hours of panel building. Panel building is roughly 10% of the total man-hours. If half of the welders are no longer necessary during panel building because of this robot, it means that from the total man-hours roughly 2,5% is reduced. In the low wage country of Cuba, the man-hours are 10-20% of the total costs of the ship. Therefore welding robots are considered too expensive and unfeasible for Damex.

SAW welding tractors and CO_2 welding are already being used, except when the power fails. As stated in chapter 1, the electric power grid used to be in bad state, but it is being fixed.

The current emergency power generator can only power a few electrode welding guns. Concerning fillet welding, CO_2 welding is roughly 2 times faster than electrode welding (DSKo welding standards).

Weld tractors are slightly more expensive than manual CO2 welding guns and can work everywhere (even outside). Single weld gun tractors (SAW and fillet) are not necessarily faster than manual CO2 welders. However the welding quality is constant (less rework) and the tractors are powered by rechargeable batteries. This means that they do not directly depend on the power supply. Dual gun fillet weld tractors (which use CO2 weld guns) weld profiles 2 times faster than a manual CO2 welder, since this tractor can use two weld guns simultaneously. Guided magnetic wheeled weld tractors can weld straight and curved profiles on plates. Therefore mechanized fillet and SAW welding tractors are considered feasible.

The mechanized welding scenario consists of mechanized panel welding by dual gun welding tractors. This means that welding throughput time remains the same, but the welding man-hours are halved (initially 2 welders are required, in the new situation only 1). Mechanized welding can also be applied during ship erection, but no direct process time is reduced. Welding quality is improved, which may reduce rework man-hours. However, when the ship is erection inaccurately, the rework remains. Because there is insufficient data about rework, this is not taken into account.

7.7.5 Bigger plates scenario

Currently small (6 x 2,5 meters) plates are being used, because of the lack of big transport means. When these transport means are available, using bigger plates (12 x 2,5 meters) has advantages. Direct advantages are less panel building hours since less tack welding and welding hours. Also less parts to transport means a reduction in transport requirement. Profile prefabrication is considered to take place in the steel part processing.

The bigger plates scenario consists of using bigger plates during panel building, which reduces the parts/panel area index.

7.7.6 Maximum hot section outfitting

Sections can be fitted with more outfit than done currently. In this case only hot outfit and conservation is considered. The following numbers are based on Damex management estimates and literature [23]. Cold outfit is not yet fitted.

Table 24. Maximum section hot outfit parts percentages

	Section outfitting	Block outfitting	Dry ship outfitting	Wet ship outfitting
Hot outfit (%)	85	n/a	15	0
Cold outfit (%)	n/a	n/a	65	35
Paint (%)	80	n/a	20	0

When more outfit is fitted before ship erection, work can be done more parallel. This means that the total throughput time is reduced. Maximum hot section outfitting and painting is a scenario.

7.7.7 Block building

Blocks are generally being built to reduce the time needed at the slipway. Block building is generally beneficial when more sections are produced than can be assembled at the slipway. Else the blocks are only waiting, which costs space. Block building is a scenario.

7.7.8 Maximum section/block outfit scenario

Section/block outfit in this case means fitting cold outfit in blocks or sections that are fully fitted with hot outfit and conservation. This scenario is only possible when sections are fully fitted with hot outfit and are fully painted. Numbers are based on Damex management estimates and literature [23].

Table 25. Maximum section/block outfit parts percentages

	Section pre-outfitting	Section/block outfitting	Dry ship outfitting	Wet ship outfitting
Hot outfit (%)	85	n/a	15	0
Cold outfit (%)	n/a	65	20	15
Paint (%)	80	n/a	20	0

When more outfit is fitted before ship erection, work can be done more parallel. This means that the total throughput time is reduced, even more than maximum hot section outfit.

8 CALCULATION TOOL

Designing an optimal shipbuilding layout for cost efficiency is an optimization problem. Optimization means that the best option must be chosen from all feasible options, which means options that meet certain criteria. The process model from chapter 5, the productivity improvement measures of chapter 7 and WBS from chapter 3 give a lot of options.

The problem in this research is that there are a lot of options of which feasibility is unclear and not yet quantified. Also, options that are feasible for specific sub-processes can be less efficient in one sub-process, but in a sub-process in a later stage this can be more than won back. This means that the best measure cannot be chosen per sub-process. All options have to be calculated over the whole ship assembly process and compared. The easiest way to do this is by using a computerized model. In this chapter the requirements for and the features of a computerized model are described. No secondary research question is answered, since a computerized model is a tool and not a goal.

8.1 Complexity of problem

As previously stated, a ship is a complex product that requires a variety of production processes, as laid out in chapter 5. The Damex targets have to be achieved by a range of feasible production method scenarios (chapter 7), for a range of ships (chapter 3). The demands are that the cost price per ship is to be reduced, and by doing that, the production capacity per year of the shipyard is increased. The current production process of Damex is used as a point of reference for the new situation. Either from the product mix or the production method range, the number of possibilities is big.

There are two ways to determine such a problem. The first is calculation by using MS Excel. This is the easiest, but also the least accurate method, since it only calculates averages. However, as stated in chapter 5, considering some margins of safety for machines and production area, these averages can be made more valid. Sufficient information is available to calculate average production parameters.

The second way is to simulate the entire shipyard. This is the hardest, but also the most accurate way to determine the resources. However, simulation requires very detailed product and production data, which is not at hand. Furthermore, a valid simulation of the entire shipyard will probably take years to complete, and this time is not available.

Table 26. Computerized model type selection

	Required accuracy	**Required and available data level**	**Effort relative to purposes**
Calculation model	+	+	+
Simulation model	++	-	--

The qualitative assessment shows that this is a problem for simple calculation. Therefore a computerized calculation model is used, made in MS Excel.

8.2 Computerized Damex production capacity calculation model

The selection process of this optimization project is done in a calculation model. In this section the process of developing a computerized calculation model is described.

The model is to follow the level 1 process model, stated in chapter 5. The black boxes produce the output of the level 1 product model, as stated in chapter 3. How much products are produced or which building method or strategy is used, is controlled. This is shown schematically in the following figure.

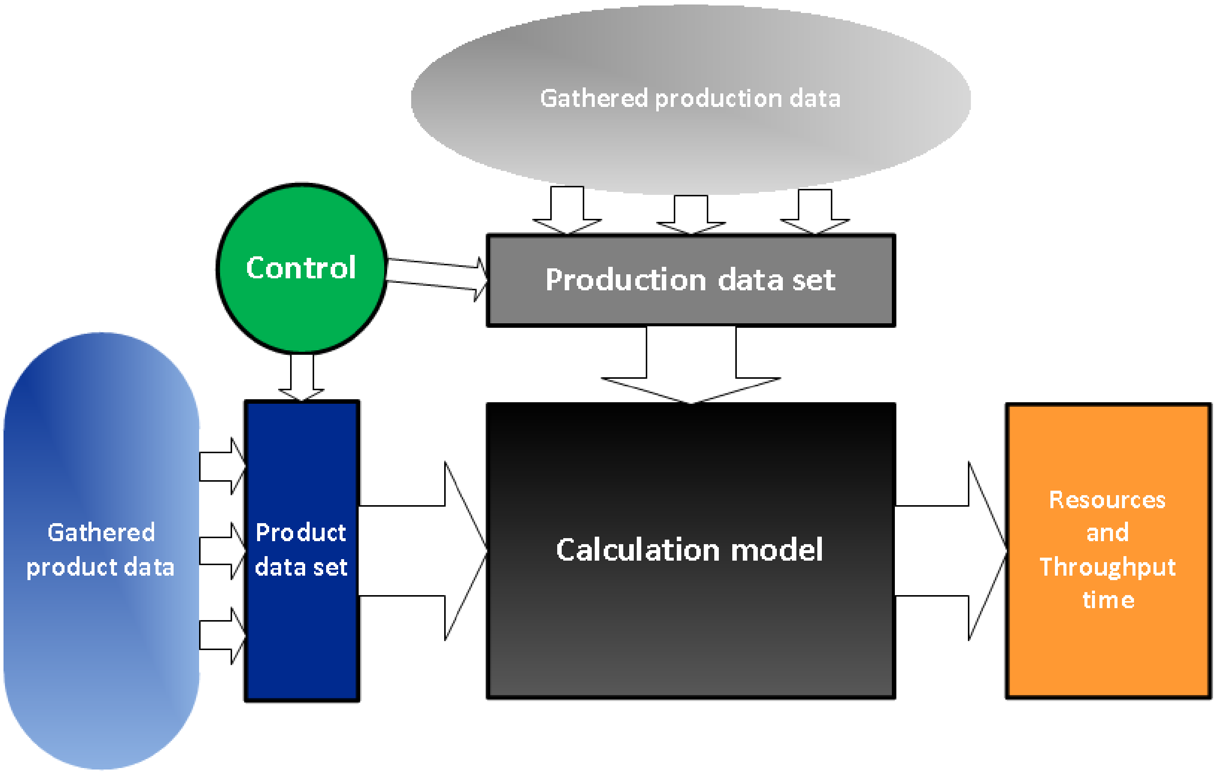

Figure 59. Calculation model representation

The calculation per sub-process is done by using Little's Law. The cycle time is calculated by the number of products that is to be produced per year. If 5 products are to be produced per year, the cycle time will be 1/5 of a year. The throughput time is dependent on the product and the production time estimator. Both will determine the average work-in-progress, or the number of products that are being produced parallel. This number, including the in chapter 5 mentioned margins of safety, will determine the number of required resources.

The overall throughput time of the ships is determined by the local throughput times of the intermediate parts. However, many of the processes run parallel, which means the overall throughput time is determined by making a planning.

The number of employees is set constant. This is done because calculations have to be made, and if all is variable this is not possible.

8.3 Validation of a computerized model

When developing a computerized model, the validity of the model has to be assured constantly. According to Sargent [7] this is to be done in a way as represented in figure 60:

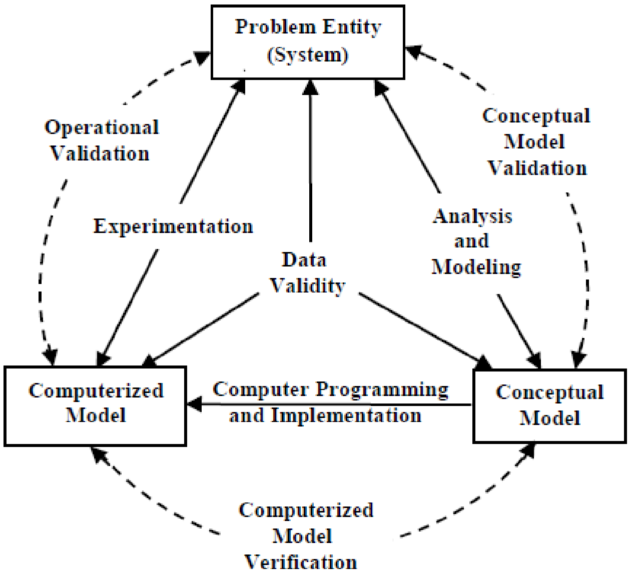

Figure 60. Computerized model validation (Sargent [7])

The problem entity is the system that is to be modeled, in this case building ships at Damex. The conceptual model is the logical representation of the problem entity in this study, in this research the process model. The computerized model is the conceptual model implemented in the computer.

In this research the problem entity is a big and complicated system. Even at a high level, analysis of this system and validation has taken a lot of time. In order to understand and be able to model the problem entity at level 1, the level 2 processes have to be understood well.

The conceptual model is validated by determining if the underlying theories and assumptions of the conceptual model are correct, and the model representation is 'reasonable' for the intended purpose [7]. In this case the checking of underlying theories and assumptions is checked by consulting with experts both at DSGo and Damex, and own observations at Damex and other shipyards. Checking whether the model representation is reasonable for the intended purposes is checked by comparing the output of the model with the research questions and design targets stated in chapter 1. Furthermore the used data, both product and production data, is to be constantly checked for validity.

Computerized model verification ensures that the computer implementation of the conceptual model are correct. The computerized model is to be error free. This can be done statically and dynamically [7]. Static verification is done by walking through the model. Dynamic verification can done by testing the model's input-output relations, for example by the input of extreme values. However, problems in dynamic verification can be caused by bad data or a faulty conceptual model [7].

When these checks are satisfactory, the model is verified and validated.

9 DAMEX PRODUCTION CAPACITY CALCULATION MODEL

The ship WBS and scenarios are determined in chapter 3 and the ship assembly process is modeled into a system in chapter 5. How the ship assembly's resources can be calculated is shown in chapter 6 and how these processes' productivity can be improved by using different productivity increasing scenarios is stated in chapter 7. All these scenarios can be put into a computerized calculation tool to help finding solutions, which is explained in chapter 8. In this chapter the scenarios of chapter 3 and 7 are put into the calculation model explained in chapter 8.

The calculation model is used to calculate required resources and throughput time of (intermediate) products of the WBS. Both are dependent on the productivity increasing scenarios and the product characteristics. The calculation model represents the level 1 ship assembly model as stated in chapter 5.

No secondary research question is answered in this chapter, since this chapter describes the application of the previous analysis of the ship assembly processes into the tool described in chapter 8.

9.1 Application of product and process model into calculation model

First of all, every influencable sub-processes are modeled individually. The report is too small for to mention every sub process model. Therefore only the main panel building process is elaborated.

As mentioned in chapter 1 and 7, the employees are set constant. At Damex there are roughly 100 workers directly involved in the ship assembly process. Since Cubans work 2200 hours per year, this means there are 220 000 man-hours available.

9.1.1 Main panel building

The required output for 2 Sla5612 ships is 148 main panels, which correspond with 5156,3 m2 of main panels. The input is 3258 steel parts (plates and profiles), which all weigh more than 50 kg.

Workers:

For this ship type the production data show: 1,31 hours/m2. These hours correspond with 0,63 parts/m2. The panel building process requires 2 panel builders and 2 welders per main panel, which take respectively 55% and 45% of the man-hours. The total panel building man-hours are therefore 148*1,31*2*0,55=7430 man-hours. The welding hours are 148*1,31*2*0,45=6079 man-hours.

Production machines:

Production crane moves are required to position the steel parts at their building position. There are 3258 steel parts to move, which take an average of 0,12 hours (average of plates and profile crane move hours), which result in a total of 398 nett crane hours.

Transport machines:

Small transport means are required to move the plates and profile bundles to the production location. Also they are required to move the movable shelters two times (plate-field assembly and profile to panel assembly) on and off per main panel. This requires 1602 transport moves of 10 minutes, which results in 267 nett crane hours.

Heavy transport means are required when the plate-field is to be turned, and when the panel is to be moved to the end buffer. This means the 148 main panels require a heavy crane 2 times. The average time is 2 hours, which means that the nett heavy crane hours are 596 hours.

Area:

The area is calculated by multiplying the average work in progress by the average area per main panel, plus the standard deviation, as explained in chapter 7. The average work in progress is 1,31*5156,3/2200=3,07. The average plus one standard deviation main panel area is 62 m2. This means that the required production area is 190 m2, which is bigger than the maximum main panel of 113 m2. Considering an input buffer of 36, and an output buffer of 113 m2, the total required main panel area 340 m2.

9.1.2 Variation in building methods for main panels

Bigger plates scenario: Bigger plates result in less parts per m2, which results in less man-hours per m2. For main panels only half of the plates have to be used. Also less plates have to be transported and positioned, which results in a reduction of required cranes. However the crane must be able to lift these bigger plates.

This results in a parts per m2 of 1,17. The resulting man-hours are 6687 and 5471 for panel builders and welders. Which means a 10% reduction in main panel building hours. Light transport and production crane hours are reduced by 25%.

Fully roofed production scenario: When the production location is covered by a roof, and for the rest all production methods and means remain the same, less small transport moves are required, since there is no more need to move the movable shelters. This results in 38% reduction of small transport moves.

Also workers do not have to wait for better weather anymore. This reduces man-hours and throughput time by 15%. Reduced throughput time also reduces the required area, as stated in chapter 6. The same products have to be made, which means the same number of production and transport machines are required.

Mechanized welding scenario: Plate-field butt welding is already mechanized at Damex by using SAW welding tractors. However, profile welding can be mechanized as well, by using dual gun welding tractors. The welding speed itself will not increase, since at Damex 2 welders were used. But one welder can do the job of 2, which means a welding man-hours reduction of 25%.

Minimum waiting for production and transport cranes and forklifts scenario: Waiting times for production and transport machines are minimized. This reduces man-hours and throughput time by at least 20%. Reduced throughput time also reduces the required area, as stated in chapter 6. The same products have to be made, which means the same number of production and transport machines are required.

More variations in building scenario are not applicable for panel building.

9.1.3 Application for all other processes

All other processes are implemented in this way. As with panel building, not all scenarios are applicable per sub-process.

9.2 Throughput time of ships estimation

The throughput times of the ships are of course dependent on the local sub-processes' throughput time. But since most processes have an overlap because of parallel building, an analysis is made to calculate this. In all cases the minimum total throughput time, including minimum slipway throughput time is assumed.

9.2.1 Current building method

Throughput time is estimated by setting up a building schedule for the ship. The activities on this schedule overlap each other. The overall throughput time is determined by adding the required local throughput times, starting from the end. However, for section building this process is started from the beginning, since it is easier to estimate the interval time of the sections. Both methods are combined during ship erection. The method of determining the normative total throughput time for a Stan Tug 2208 following the current building methods is shown in the following table.

Table 27. Throughput time planning STu2208 example

Process	Normative time	Remarks
Steel part processing	2 weeks	Preparing the steel parts for at least one section
Sub panel building	1 week	Building the sub panels for one section
Main panel building	1 week	Building the main panels for one section
Rigid main panel building	1 week	Building the rigid main panels for one section
Section building (incl. pre-outfitting and paint)	13 weeks	Building the first two sections of 12 weeks with one week separate start. Minimum hot outfit but no painting is taken into account.
Block building (incl. block outfitting)	n/a	Not performed currently
Ship erection	10 weeks	Theoretically could happen in 5 weeks, but due to Cuban circumstances 10 weeks are required (broken crane, weather)
Ship dry outfitting	4 weeks	All necessary underwater outfit is fitted during this phase (painting, shafts, rudders propellers etc.). Also the main engine is fitted during this phase. Can be longer when slipway is not a bottleneck.
Ship wet outfitting	14 weeks	The outfit is finished during this phase. Can be shorter when the slipway is not a bottleneck.
Commissioning and trials	6 weeks	Systems are tested. Harbour and sea trials are performed.

The table is put into time in the following graph. The shaded bars represent non-normative local throughput time. Blue represents casco, and red outfitting time. The total throughput time of a STu2208 in this case is 52 weeks, so one year. Updated Damex schedules confirm this.

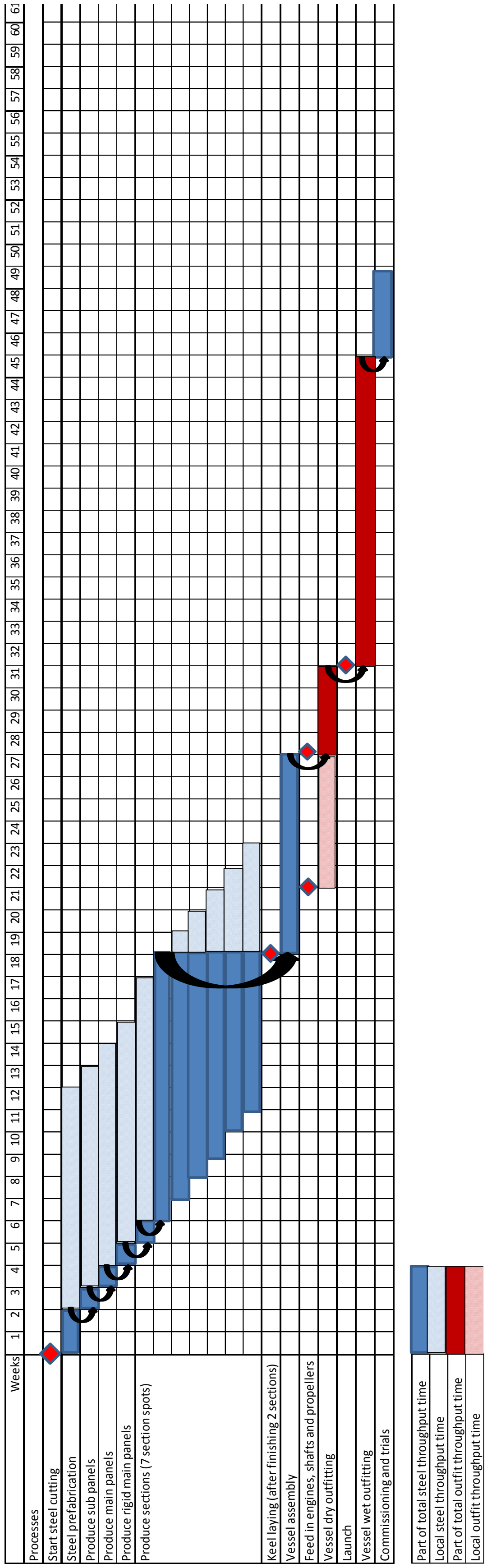

Figure 61. Throughput time planning Stan Tug 2208 example

When the intermediate products/ building strategy is changed, this affects the throughput time. The other building strategies are put into the calculation model in the same way. The considerations are described in the following sub-sections

9.2.2 Insufficient parallel section building space

When there is not enough space to build sections, for example 4 spots to build 7 sections, sections must be built after each other. This results in a total throughput time increase of an entire section (12 weeks). More storage or slipway time for finished sections is required. This is shown in appendix C.

The total throughput time in this case is 64 weeks. Having too few section spots to produce the sections for a ship, greatly affects the total throughput time. This is the case of Damex building a SLa5612 and SPa 4207.

9.2.3 Maximum section outfitting

Sections can be pre-outfitted more than currently. Hot works can be (almost) completed and the section can be painted. This can be done parallel to each other. Wet outfitting time is greatly reduced by this. This is shown in appendix D.

9.2.4 Block building

Blocks can be built from sections to reduce the amount of time that is required at the slipway. This is shown in appendix C.

9.2.5 Maximum block/section outfitting

Total throughput time can be further reduced by maximum outfitting of sections or blocks. Block/sections outfitting cannot be done when the surface is not painted, and painting cannot be done when (most of the) hot works are still to be done. This shortest total throughput time at the current efficiency level (local throughput times) is approx. 43 weeks, which is about 2 months shorter than the current time. This is shown in appendix E.

This total throughput time can be further reduced when local throughput times are reduced when non value adding hours are reduced.

9.3 Validation of calculation model

Validation of the calculation model begins with ensuring the calculations correspond with the conceptual model (and the conceptual model corresponds with the reality of course). This is done by paying attention during implementation and checking with extreme values.

The calculated values of the resources also have to correspond with the system entity, or in other words reality. Reality in this case is the available historical data and observations.

9.3.1 Man-hour distribution per ship validation

To assure validity of the model first the most valid data is checked: the overall man-hour distribution per ship. Since ship assembly is the focus of this research, the problem entity must also be ship assembly. Overall production hours are found at different sources, each with its own goals and assumptions.

Some ships have been built before and some are not. Some ships have been built under other circumstances than other ones. Therefore some data is more reliable than other.

Table 28. Man-hours per ship calculation validation

	Calculation current situation	DSGo IDK calculation (IDK *2)	Damex calculation (IDK *2,5)	Damex planning	Damex historical data
STu2208	40000	48000	DSGo	42500	40100
SLa5612	106000	100000	127729	106533	118837
SPa4207	78000	63250	79063	92167	N/A

This table shows that there is a certain spread in sources of the total man-hours. Historical data is the most reliable, however in this research it is also the most lacking. Only the STu2208 has sufficient data (4 completed ships and 6 comparable ships), while the Sla5612 has only one completed ship. The first SPa4207 is currently being built.

The Damex planning and calculation can be seen as reliable, but since there is no historical data about the SPa4207, there is a big spread. This can be explained by the interests of both parties: DSGo calculates a low cost (buyer's interest) and Damex calculates a bigger cost (builder's interest).

The next validation step is to look at the man-hour distribution over the shipyard. There is no historical data available regarding shipyard processes. Therefore this step is qualitatively by confirming it with experts.

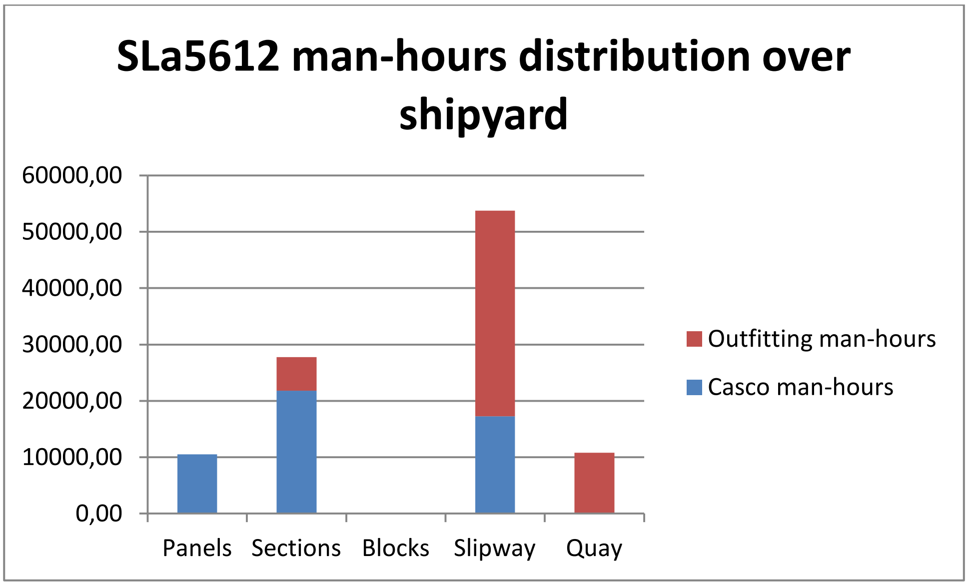

Figure 62. Stan Lander 5612 man-hour distibution over shipyard from calculation model

Since the overall man-hours distribution data corresponds with the calculated values, the sub-process man-hours are checked with extreme values to confirm the functioning of the model.

When different scenarios are calculated, the results are compared to the expected results. For example, when performing block building, the man-hours remain the same, since the same process is performed under (roughly) the same circumstances.

The functioning of the model has been tested by (static) walking through the entire process and checking for error and (dynamic) by applying large input numbers. The output in the model was as expected.

9.3.2 Transport and production cranes and machines

The only data available of transport and production cranes and machines is the number of machines that is observed at Damex at each sub-process. Therefore the only validity check is the number of theoretical machine hour corresponds with the values calculated by the model.

Table 29. Cranes and transport machines validation

	Machine hours	Theoretical machine number (95% uti.)	Theoretical machine number (50% and 70% uti.)	Available cranes
Production cranes	3711	1,7	3,4	2
Transport light	2743	1,3	2,5	2
Transport heavy	1920	0,9	1,2	2

Compared to the overview of the number of cranes and other transport means in chapter 6, the regular crane failures, these numbers show the high utilization grade of the current cranes (6 instead of 7-8 machines).

Note that these numbers still have to be assigned to a department. This is done in chapter 9 and 10.

The results are compared to the expected results. For example, when building under a solid roof (covered production), crane hours must be reduced because there is no more need to move shelter roofs.

The functioning of the model has been tested by (static) walking through the entire process and checking for error and (dynamic) by applying large input numbers. The output in the model was as expected.

9.3.3 Direct production area

The direct production area of the problem entity is only known of the observed work in progress. In figure 29 in chapter 4 the layout of the direct production area is sketched. The values of these areas must correspond with the similar building scenario, 2 Sla5612 ships per year.

Table 30. Production area validation

	Calculation model 2x Sla5612	As-is
Steel part processing	588	600
Panels and sections	2240	2200
Slipway	58	58
Quay	58	58

Both areas look very similar. The panel and section area have been summed in order to make the model comparable to the present situation, in which there is no subdivision.

The functioning of the model has been tested by (static) walking through the entire process and checking for error and (dynamic) by applying large input numbers. The output in the model was as expected.

10 PRODUCTION CAPACITY CALCULATION RESULTS

Now the analysis products, processes and productivity improvements are applied into a computerized calculation model, the different scenarios can be tested for the production increase targets as stated in chapter 1. In this chapter the final secondary research question is answered:

- **What influences do the productivity increasing methods have on the use of Damex' resources?**

The results of the calculations performed in the calculation model are listed in this chapter. All calculations are done per individual scenario to gain an as reliable as reasonable possible result. In order to keep the calculation results comparable, all scenarios produce the same amount of ships, as described in chapter 3. This way the direct costs per ship in man-hours and the throughput time are compared.

As stated in chapter 1, the total direct ship assembly workers are set constant, which result in a current production capacity of 2 Stan Lander 5612, 3 Stan Patrol 4207 or 5 Stan Tug 2208 ships per year.

First the production scenarios are shown regarding man-hours and throughput time per ship. After that, given the total man-hours per year are set constant, the new shipyard capacity per scenario is calculated.

10.1 Production capacity results per scenario

For all scenarios the initial two main results are calculated: man-hours and throughput time per ship, which are the main cost reducing factors.

10.1.1 Direct ship assembly man-hours and throughput time

First the total direct ship assembly man-hours and throughput time per ship are presented.

Table 31. Direc ship assemblyt man-hours and throughput time

	SLa5612		SPa4207		STu2208	
	Manhours (mh)	Throughp. time (wk)	Manhours (mh)	Throughp. time (wk)	Manhours (mh)	Throughp. time (wk)
As-is	106385	101	78853	86	39893	48
Bigger plates	105652	101	78416	86	39652	48
Mechanized panel welding	105494	101	78329	86	39570	48
Covered production	90963	93	67293	75	34089	48
Minimum waiting for cranes etc.	75542	87	55752	64	32154	48
Maximum section hot outfit and conservation	98570	95	70001	82	36184	44
Maximum section cold outfit	95210	82	66385	78	34066	39
Block building	106385	101	78835	86	39893	48

Maximum block cold outfit	95210	82	66385	78	34066	39

The financing costs are determined by the time that is required to produce the product, which is the total throughput time. As can be seen in the table, the total throughput time is affected by the maximum hot and cold outfitting during earlier stages of the production process, and the following parallel working, but also very much by producing according to the Lean shipyard methods.

An interesting result is that block building does not have any effect on the total throughput time. This is because the slipway is not fully occupied in this production quantity. Since the slipways are not fully utilized, there is no need to build large blocks.

10.2 Testing individual scenarios against production capacity targets

Since the number of workers is set constant and the man-hours per ship are reduced, more ships are to be produced. How much extra production is required is dependent on the man-hour efficiency percentage compared to the as-is situation. The inverse of this percentage is the capacity increase of the scenario. This is shown in table 32. Since the actual amount of ships that is to be built in the future is not certain, the average production increase per ship type is chosen to calculate with. The only exception is the minimum machine waiting time scenario. Since the reference STu2208 were built under the conditions of working cranes (as explained in chapter 5 and 6), and to keep the conditions as conservative as possible, this is the normal as-is scenario.

Table 32. Production increase

	Man-hour % compared to as-is per shiptype			**Production increase % compared to as-is per shiptype**			**Average increase %**
	SLa5612	SPa4207	STu2208	SLa5612	SPa4207	STu2208	**Production**
As-is scenario	100,0%	100,0%	100,0%	0,0%	0,0%	0,0%	**0,0%**
Using bigger plates	99,3%	99,4%	99,4%	0,7%	0,6%	0,6%	**0,6%**
Mechanized panel welding	99,2%	99,3%	99,2%	0,8%	0,7%	0,8%	**0,7%**
Covered production	85,5%	85,5%	85,5%	17,0%	17,0%	17,0%	**17,0%**
Minimum machine waiting	71,0%	70,7%	80,0%	40,8%	41,4%	25,1%	**25,1%**
Maximum hot section outfitting	92,7%	88,8%	90,7%	7,9%	12,6%	10,3%	**10,3%**
Maximum section outfit	89,5%	84,2%	85,4%	11,7%	18,8%	17,1%	**15,7%**

Block building	100,0%	100,0%	100,0%	0,0%	0,0%	0,0%	**0,0%**
Maximum block outfit	89,5%	84,2%	85,4%	11,7%	18,8%	17,1%	**15,7%**

From these values can be concluded that no individual scenario can provide the required 50% production increase.

10.3 Deriving feasible production capacity improvement concepts

Since no individual scenario can provide the required 50% increase in production capacity, combinations have to be made. Scenarios that do not have any production capacity increase are no longer taken into account.

When the scenario combinations that meet the 50% production capacity increase are found, these combinations are tested for the 200% production capacity increase target.

10.3.1 Productivity improvement scenarios that increase production capacity by 50%

Since the individual scenarios do not meet the 50% production capacity increase target, combinations are made that do meet this target. These are stated in table 33. First the remaining scenarios are stated. The impossible combinations are stated, plus a qualitative assessment of the required investments per scenario.

Table 33. Production increase scenarios

Pr. Cap. Incr. scenarios	Pr. Cap. increase	Feasible combination?	Magnitude of investm.	Investment remarks
Using bigger plates	0,60%		Low	Sizable transport required, but less than currently
Mechanized panel welding	0,70%		None	Only new tools required
Covered production	17,00%		High	New halls required, including factory machines
Minimum machine waiting	25,10%		Medium-high	New machines required, more when in covered production
Maximum hot section outfitting	10,30%	No intermediate product change	Low	More area and production cranes required
Maximum section outfit	15,70%	No intermediate product change	Low	More area and production cranes required
Maximum block outfit	15,70%	No intermediate product change	Low-medium	More area and production cranes required

No combination of two individual scenarios reaches a production capacity increase of 50%. Therefore a minimum combination of three scenarios is required.

10.3.2 The ‘cheap’ uncovered scenario combination

As can be seen in table 33, covered production requires the highest investment, since new halls have to be built and the current field equipment cannot operate under a roof. Therefore first the best scenario without covered production is assessed. This scenario is called the ´cheap scenario´.

This scenario consists of the bigger plates, mechanized panel welding, minimum machine waiting (uncovered) and maximum section outfit scenarios. Since this scenario has no new halls, the sun shelters are still used. This increases small transport crane hours by 11% compared to the covered scenarios.

This scenario combination increases the production capacity by **46,6%**. This is very close to the target, but not enough. For the sake of completeness this scenario is assessed for investments, since it is so close to the target and investments are relatively low.

10.3.3 Covered, minimum waiting, maximum hot section outfit combination

The first covered production scenario consists of minimum waiting for machines and maximum hot outfit in the section intermediate product. This scenario combination increases the production capacity by **61,4%**. This is enough to achieve the target of 50%. This scenario is called the ´maximum hot section outfit scenario´.

10.3.4 Covered, minimum waiting, maximum section outfit combination

The second covered production scenario consists also of minimum waiting for machines and maximum outfit of the section intermediate product. This scenario increases the production capacity by **69,4%**. This is also enough to achieve the 50% target. This scenario is called the ´maximum section outfit scenario´.

10.3.5 Covered, minimum waiting, maximum block outfit combination

Block building does not increase the productivity of the shipyard. However, it can spare the construction of another slipway. The blocks can be, just as the sections from the previous scenario, be fitted with maximum outfit. Just as the previous scenario, these measures increase the production capacity with 69,4%. This is enough to achieve the 50% target. This scenario is called the ´maximum block outfit scenario´.

However, calculations show that for ship erection and essential outfitting before launch at 200% production increase there is plenty of time for this to happen on one slipway. And since there are a maximum of 2, and if necessary 3 slipways available, the slipway is not a bottleneck. *Therefore this scenario is not taken into account.*

10.3.6 Scenarios in combination with mechanized panel welding

Production capacity of the former scenarios can be further increased by applying mechanical welding. There is no investment required for mechanical welding (tools are not considered machines or facilities, see chapter 1, 4 and 5). Therefore this individual scenario is always applied in the combination scenarios.

10.3.7 Scenarios in combination with the using of bigger plates

For using bigger plates during production an investment in transport is required, though it is a small one (minimum is a cart of €15 000,-). However, fewer parts are to be transported, which mean less transport machines are required. Small transport and production cranes hours are both reduced by 5% compared to scenarios that do not use bigger plates.

Another reason is that fewer parts are to be assembled, which means less over-processing, since these is less unnecessary welding.

10.3.8 Resulting feasible production increase concepts for investment analysis

The following concepts are derived.

Table 34. Feasible production increase concepts

	Concept 1: Cheap (+46,6% prod. cap.)	**Concept 2: Maximum section hot oufit (+63,6% prod. cap.)**	**Concept 3: Maximum section oufit (+71,6% prod. cap.)**
Using bigger plates	+	+	+
Mechanized panel welding	+	+	+

Covered production		+	+
Minimum machine waiting	+	+	+
Maximum hot section outfitting		+	
Maximum section/block outfit	+		+
Block building			

The amount of other resources and their investment analysis are executed in chapter 11.

10.3.9 Productivity improvement concept that increase production capacity by 200%

As can be seen in the former section, several scenarios reach the targets of at least 50% production capacity increase. However none are close to the 200% increase. The highest production capacity increase combined scenario concept consists of the covered, bigger plates, mechanized panel welding, minimum waiting for machines and maximum section outfit individual scenarios. In this concept the production capacity is increased by 71,6%. This is not enough to reach the 200% target.

This means the number of workers has to be increased

10.3.10 Estimation of extra workers for production capacity increase of 200%

Increasing the workforce is extrapolation. The extrapolation is considered linear, which is not certain and thus not reliable. Also this extrapolation is not in accordance to the design constraints. But an indication is given about how much workers are required to increase the production capacity by 200%.

Considering employees, in the best concept the 100 current employees produce 71,6% more than the current production capacity. When producing 200% more, a workforce of 175 workers is required.

This version of the maximum section outfit concept is also The amount of other capital goods is determined in chapter 11.

11 INVESTMENT ANALYSIS AND OPTIMAL LAYOUT

The concepts that achieve the productivity targets are calculated in chapter 10. In this chapter they are assessed for the investment targets stated in chapter 1. For the best concept a new layout is made. The new layout corresponds with the required areas, the available area and the guidelines of minimum transport and motion of products.

11.1 Extra cash flow per feasible production capacity concept

First the extra cash flow per feasible production capacity concept is calculated. The extra cash flow consists of three different components: direct man-hour cost reduction per ship, direct financing cost reduction per ship and indirect cost reduction per ship. Since the production is increased, the cost reductions per ship have more effect.

However, to calculated the direct man-hour costs and indirect costs the currently used man-hour rate has to be split.

11.1.1 Deriving direct and indirect components of man-hour rate

The current man-hour rate is a combination of direct and indirect costs divided over the total direct labour man-hours per year. The direct and indirect components are derived from the current man-hour rate. Assumed is a man-hour rate of $12,-. In this man-hour rate both direct and indirect costs are incorporated.

As a reference, fellow communist (in name) country China is used. Interviews show (R. Wallace, Contracting Manager CYS) in China (DSCh) roughly 40% of the man-hour rate of $8,50 is direct labour costs. Data from the world bank show that GDP per capita in China is $8400 per year, which is $3,5 per hour. This corresponds very well with the 40%.

The GDP per capita of Cuba is $5400, which is roughly $3,- per hour. This means that 25% of the man-hour rate is direct labour costs. The difference can be explained by the higher presence of Dutch management at Damex, higher energy costs and the fact that every production asset has to be imported from the Netherlands which results in higher depreciation costs.

11.1.2 Cash flow by direct costs reduction per year

As described in chapter 10, direct man-hour costs per product are reduced when the scenarios are applied. The combinations of scenarios reduce these even more. These man-hour reductions cause that more products can be built per year, assumed that the sales increase as well and sale price remains the same. These things cause an extra cash flow. In table 35 the annual extra cash flow per ship is stated.

Table 35. Additional cash flow by direct cost reduction

	SLa5612	SPa4207	STu2208
Cheap concept (+46,6% prod. cap.)	$293.478	$326.291	$275.126
Maximum section hot oufit concept (+63,6% prod. cap.)	$400.897	$445.719	$375.828
Maximum section outfit concept (+71,6% prod. cap.)	$452.879	$503.513	$424.559
Maximum section outfit concept (+200% prod. cap.)	$791.953	$880.498	$742.430

The STu2208 has the least man-hour and thus direct man-hour cost reduction of the three ships.

11.1.3 Cash flows by financing costs reduction per year

Financing costs per product become less when the throughput time is reduced. When more products are built, this reduction is multiplied by the production increase. This is of course under the assumption that sale price remains the same.

A Dutch bank [ING, 29] shows a working capital financing interest rate of roughly 7% per annum. This is used for calculating the financing costs.

Assumed is the financing of the total product by the customer (J. Kossen) and the same selling price. When less time and thus costs are necessary, extra cash flow can be gained, since there are fewer costs for the same selling price. The financing costs are calculated under the assumption that every material is ordered before production. In reality this may not always be the case for every other shipyard.

Table 36. Additional cash flow by financing cost reduction

Financing costs (7% interest)	SLa5612	SPa4207	STu2208
Cheap concept (+46,6% prod. cap.)	\$199.830	\$326.896	\$128.145
Maximum section hot oufit concept (+63,6% prod. cap.)	\$90.009	\$147.243	\$57.720
Maximum section outfit concept (+71,6% prod. cap.)	\$233.801	\$382.468	\$149.930
Maximum section outfit concept (+200% prod. cap.)	\$408.850	\$668.824	\$262.184

The smallest change in financing costs is used for calculating the extra profit, which is the financing costs of the STu2208.

11.1.4 Cash flow for indirect costs reduction per year

Indirect costs per year remain the same, but more products are produced per year, which means less costs per product. When sales price remains the same per product, more cashflow is generated.

Table 37. Additional cash flow by indirect cost reduction

Indirect costs	SLa5612	SPa4207	STu2208
Cheap concept (+46,6% prod. cap.)	\$209.266	\$209.266	\$209.266
Maximum section hot oufit concept (+63,6% prod. cap.)	\$285.202	\$285.202	\$285.202
Maximum section outfit concept (+71,6% prod. cap.)	\$321.137	\$321.137	\$321.137
Maximum section outfit concept (+200% prod. cap.)	\$897.592	\$897.592	\$897.592

This cost reduction is of course ship independent. A higher production increase gives a higher cash flow

11.1.5 Extra cash flows per year

Since the STu2208 has the least added profit in all cases, this is chosen to make the conservative extra profit estimation.

Table 38. Total additional cash flow

	Direct	Financing	Indirect	Total
Cheap concept (+46,6% prod. cap.)	$275.126	$128.145	$209.266	$612.538
Maximum section hot oufit concept (+63,6% prod. cap.)	$375.828	$57.720	$285.202	$718.750
Maximum section outfit concept (+71,6% prod. cap.)	$424.559	$149.930	$321.137	$895.626
Maximum section outfit concept (+200% prod. cap.)	$742.430	$262.184	$897.592	$1.902.206

All extra cash flows are stated in US dollars. An exchange rate of $1,32 for every euro (€) is used (www.bloomberg.com; 1 may 2013).

11.2 Investments for feasible production capacity concepts

Producing more ships ultimately result in using more resources than the current, other than workers. Therefore these are shown in this paragraph. Investments are required for these additional resources other than workers. Machines and material has to be imported from the Netherlands.

11.2.1 Used prices of capital goods

To calculate the investments, their price is required. Since the machines and materials have to be imported from the Netherlands, the Dutch prices in euros (€) are used. When facilities are to be built at Damex, local workers are used which saves labour costs. Facilities are considered to cost half of those built in the Netherlands. These prices are based on company data of Damen Civil Services Special Projects [A. Duijzer] and Dutch price estimations [32].

Table 39. Investment prices

Prices for machines and facilities	Remarks	Price (€)
Cranes (Dutch prices)		
10 tons	13m beam	25.000
30 tons	26m beam	100.000
30 tons	39m beam	150.000
60 tons	26m beam	350.000
60 tons	39m beam	525.000
Other transport machines (Dutch prices)		
Section transporter 100 tons		100.000
Cart (12m plate size)		15.000
Forklift		25.000
Production machines (Dutch prices)		
CNC plasma cutting and marking 2x12x3m		400.000
Hydraulic plate press		250.000
Profile bending machine		150.000
Mechanized main panel lane		3.000.000
Welding robot for main panel lane		1.200.000
Guillotine plate shear		5000

Small steel plate folding machine		10.000
Mandrel pipe bending machine		100.000
Sawing machine		15.000
Prices for facilities (1/2 of Dutch prices, since less labour costs)		
Hall		€50/m3
Concrete floor		€250/m2
Crane track		€50/m*ton

These prices are indications. Prices can fluctuate and therefore these numbers are not too reliable.

11.2.2 Areas

First of all the production areas are determined. These results are shown per specific area. All panel types are considered to be built on a concrete floor in one designated space. Each have their specific buffers. The section floor is consider to contain the section building, hot outfitting, painting and (depends per concept) the section outfitting processes. During these stages the section is not transported to another place.

the slipway and outfitting quay, since they are measured in length. The maximum area for the ships is normative for the area requirement. Therefore the SLa5612 production area is taken as normative. This selection has been done in table 40.

Table 40. Calculated areas for ship assembly

Maximum area (m2) for all concepts	Panel area (m2)	Section area (m2)	Slipway (60m)	Outfitting quay (60m)
Cheap concept (+46,6% prod. cap.)	675	1900	1	1
Maximum section hot oufit concept (+63,6% prod. cap.)	675	1585	1	2
Maximum section outfit concept (+71,6% prod. cap.)	697	1934	1	1
Maximum section outfit concept (+200% prod. cap.)	970	2822	2	2

The required area for the cheap concept is, in principle, available at Damex. However, the current panel and section building net area totals only 2200 m2 (see chapter 4 and 9) because of required maneuvering space for the mobile cranes. Expanding this net area by 375 m2 is not possible on the current concrete floor. Since it will reduce the ship repair area. Current concrete floors are not suitable for this solution, since the current concrete floors are not at the same level and of the same quality. Also new crane tracks are to be installed for the new gantry cranes.

For new facilities inside a new hall a new concrete floor is required for the same reason as the cheap concept. The height and breadth of the new halls is dependent on the products that are to be built. A main panel and section's maximum width is 12m. The crane must have some extra space for the crane tracks, and therefore the crane width must be 13m. The height of the halls again is dependent on the maximum breadth of the sections, since they have to be turned. A section's maximum breadth when it has to be turned is 12m, but the length is 10m and height is 4m, which means that a height of 11 meters is sufficient. Plate fields have to be turned as well, so this also applies for the panel building area.

An initial hall width of two of the biggest main panels is used for cost reasons. When the building is wider, it will be more expensive, as well as the cranes (bigger span). A narrower hall does not fit.

The overhead crane, hook and weigh distributer also need height. The weight distributor is usually 1/3 of the maximum main panel and section breadth. The distributor forms a triangle and can hold the section stable this way [J.B.B. Teuben]. A sketch is shown in figure 63

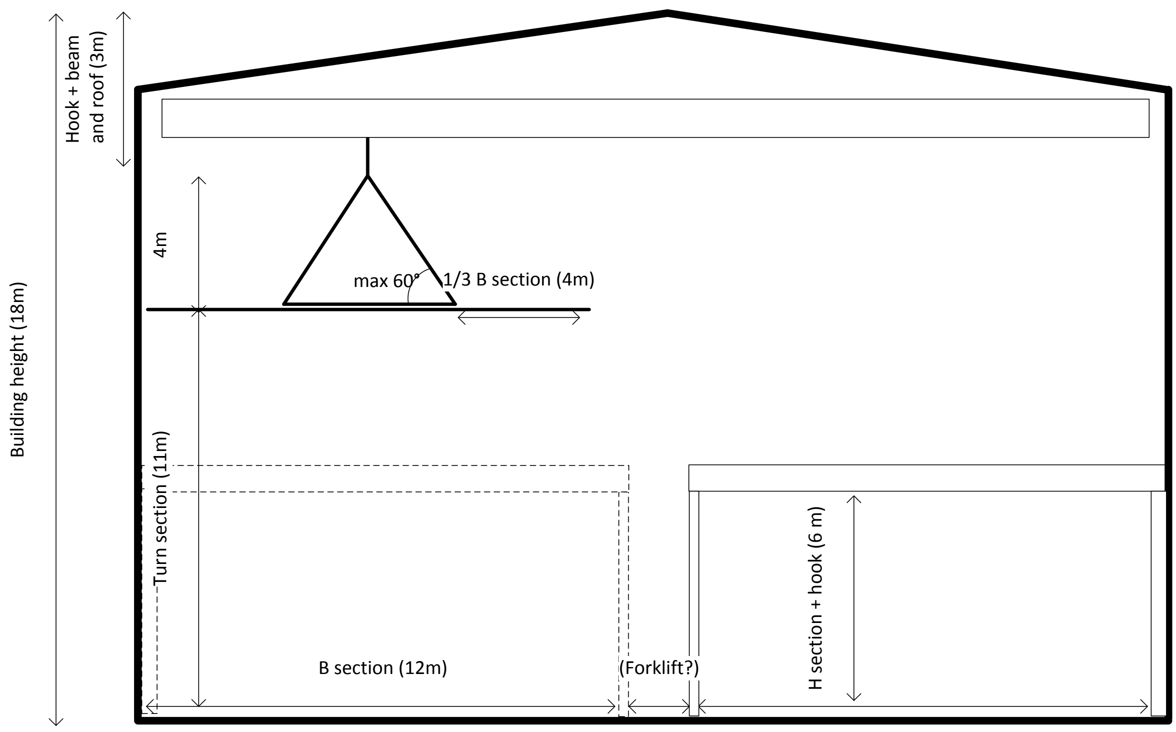

Figure 63. Cross section sketch of new panel and section building hall Damex

A forklift track of 4m is reserved in the sketch. This can be changed if the overhead cranes are used for transport.

The required area for a production increase of 200% is available at Damex. However, the hall needs to be wider than 2 building lanes for this version, or 2 separate halls are necessary. There are 2 slipways required when ship erection is done by using sections. These slipways are currently present at Damex. The two outfitting quay spots are also available.

11.2.3 Production cranes

A production crane move is generally an assembly move up to 10 tons, since it is the heaviest part they are to assemble. Production crane hours, at full (100%) utilization are calculated first and stated below. An average 50% utilization is required for them to minimize waiting. The cranes are available for the same 2200 hours per year as the workers.

Considering production cranes, the STu2208 product scenario has the most parts for panel and section building that require a crane to be assembled. Therefore these numbers are normative. At the slipway and outfitting quay the SLa5612 requires the most positioning moves.

Table 41. Calculated production cranes for ship assembly

Production crane (10t) hours in certain areas per concept	Panel area	Section area	Slipway	Outfitting quay
Cheap concept (+46,6% prod. cap.)	3179	2705	413	64
Maximum section hot oufit concept (+63,6% prod. cap.)	3508	2389	718	549
Maximum section outfit concept (+71,6% prod. cap.)	3771	3208	490	61
Maximum section outfit concept (+200% prod. cap.)	6578	5596	854	132
Number of required production cranes (10t) at 50% utilization				
Cheap concept (+46,6% prod. cap.)	2,9	2,5	0,4	0,1
Maximum section hot oufit concept (+63,6% prod. cap.)	3,2	2,2	0,7	0,5
Maximum section outfit concept (+71,6% prod. cap.)	3,4	2,9	0,4	0,1
Maximum section outfit concept (+200% prod. cap.)	6,0	5,1	0,8	0,1

The required number of cranes are not yet rounded up, since small and heavy transport cranes can also be used for ship assembly when they are in their particular area.

11.2.4 Light transport cranes and machines

Light transport is generally transport move up to 10 tons, which numbers are stated below at 100% utilization. Light transport utilization is required to be 50% to minimize waiting. For the investments in the small production and transport machines, the 50% theoretical utilization is assumed. Which means the crane hours numbers are doubled and divided over 2200 hours to calculate the number of cranes per specific area.

The STu2208 scenario has the most required light transport moves for the panel and section area and is therefore normative. For the slipway and outfitting quay the SLa5612 scenario has the most light transport moves.

Table 42. Calculated light transport machines for ship assembly

Light transport cranes (10t) in certain areas per concept	Panel area	Section area	Slipway	Outfitting quay

Cheap concept (+46,6% prod. cap.)	3697	2351	225	52
Maximum section hot oufit concept (+63,6% prod. cap.)	2754	1378	924	514
Maximum section outfit concept (+71,6% prod. cap.)	2960	1652	267	61
Maximum section outfit concept (+200% prod. cap.)	5163	2882	465	107
Number of required light transport (10t) machines at 50% utilization				
Cheap concept (+46,6% prod. cap.)	3,4	2,1	0,2	0,1
Maximum section hot oufit concept (+63,6% prod. cap.)	2,5	1,3	0,8	0,5
Maximum section outfit concept (+71,6% prod. cap.)	2,7	1,5	0,2	0,1
Maximum section outfit concept (+200% prod. cap.)	4,7	2,6	0,4	0,1

Light transport can be done by using forklifts or by using overhead cranes. Overhead cranes are more expensive than forklifts, but require a wider hall. Widening of the hall is also expensive.

The above data is based on the assumption, based on the current situation, that every plate, profile bundle, sub panel, small parts crate or heavy outfit part is transported individually. When the overhead crane is used for transporting these materials, this is of course not the case. Plates can be placed on a flat rack, sub panels in a crate etc. This greatly reduces the number of transport moves, but there is no data how much exactly. Therefore is assumed that one extra heavy transport crane is required for transporting packed light transport parts.

11.2.5 Heavy transport cranes and machines

Heavy transport utilization can be higher than 50%, since it is usually planned and therefore predictable. , and heavy transport moves are up to 80 tons. This transport however can be done by a section transporter. The heaviest crane must be able to lift the biggest section and some hot outfit, which is 60 tons max (see section building appendix B). The lifting of this heaviest part of 80 tons on the section transporter or other platform can be done by using the 60 tons crane in tandem with a smaller crane.

The SLa5612 scenario has the most required heavy transport moves and is therefore normative.

Table 43. Calculated heavy transport machines for ship assembly

Heavy transport (>10t) cranes in certain areas per concept	Panel area	Section area	Slipway

Cheap concept (+46,6% prod. cap.)	858	1009	1102
Maximum section hot oufit concept (+63,6% prod. cap.)	947	1114	1011
Maximum section outfit concept (+71,6% prod. cap.)	1018	1197	1240
Maximum section outfit concept (+200% prod. cap.)	1776	2088	2164
Number of required heavy transport (>10t) machines at 70% utilization			
Cheap concept (+46,6% prod. cap.)	0,6	0,7	0,7
Maximum section hot oufit concept (+63,6% prod. cap.)	0,6	0,7	0,7
Maximum section outfit concept (+71,6% prod. cap.)	0,7	0,8	0,8
Maximum section outfit concept (+200% prod. cap.)	1,2	1,4	1,4

The production and small transport inside the slipway hall and at the outfitting quay are already available. There are 2 cranes of 2x 10 tons each inside the slipway hall, and there is a tower crane at the outfitting quay. Transporting sections inside the slipway hall is currently not possible, and therefore a section transporter is required.

11.3 Testing feasible production capacity concepts against investment targets

In this section the feasible production concepts, which increase production by at least 50% compared to the as-is situation with a constant workforce, are tested for the investment targets of 12% internal rate of return and a positive net present value with an annual discount rate of 12% over 15 years (Dutch technical lifespan of cranes and forklifts). Since Cuba has a relatively investor unfriendly political climate, the lowest investment is preferred.

The steel parts processing scenario testing is also included in this section, which is tested over a lifespan of 10 years (average lifespan steel part processing machines [32]).

Testing the concept that increases the production by 200% is not included, since the number of workers are not available. In the future this option can be feasible, since there is room for a second building when the first building is placed.

11.3.1 Cheap Damex concept

This version's facilities are outside. No hall is required and some cranes and forklifts are already available. The slipway and outfitting quay transport and production machines are already there.

Workers are complaining about heat, and Damex wants to invest in shelter for them [R. Kentie; I. Campos Castro]. Some shelter for the workers can be provided by movable halls, which have to be imported from the Netherlands. These cost €600 000,-.

For panel and section area the requirements are 5,4 production cranes, 5,5 light transport machines and 1,3 heavy transports. Currently there is one production crane (mobile crane) available, two transport forklifts and two heavy cranes. This means that there is a shortage of 4,4 production cranes and 3,5 light transport machines.

For these small cranes, crane tracks are required. These have to be 2575/13= 200m of tracks that can hold 10 tons.

Table 44. Cheap concept investments

Location	Measurements	Price indication	Machines and facilities
Panel facilities	200 m, 10 tons	€ 100 000	Crane tracks
Panel machines		€ 100 000	2 small cranes (10t), 2 forklifts
Section machines		€ 125 000	3 small cranes (10t), 2 forklifts
Slipway machines		€ 100 000	1 big transporter to move section into the new slipway hall (100t)
Concrete Floor		€ 650 000	For a leveled surface
Other machines		€ 205 000	Materials storage crane and tracks; outfit production machines
Total		**€ 1280 000**	

Minimum of $612 000,- per year extra cashflow when building corresponding to the cheap method. Corresponds with €464 000,-.

Internal Rate of Return over 15 years is 36%. The NPV is positive within 4 years, and within 15 years it is €1 880 000,-. The investment is earned back within 3 years.

This version does not fulfill the production increase target of 50% and therefore is not optimal. This option is therefore not chosen in this research. However, it can be chosen when the company does not want to risk a big investment.

11.3.2 Maximum section hot outfit concept

This concept is calculated with one heavy crane for transporting light transport part packages, instead of three forklifts and a forklift lane, since one crane is cheaper than a wider hall and the forklifts.

Concrete floors, halls and crane tracks are required. The slipway and outfitting quay transport and production machines are already there. A floor of 2260 m2 has to be constructed. A covered section building and hot outfitting hall of (88x25x18) and a separate section conservation hall (paint shop, 12x14x8) is to be constructed. The separation is because of the required resources. Section building an hot outfitting requires two big cranes and sufficient height for turning the section, but section conservation does not require this. A separate section conservation hall reduces the investment. Transport is done by the section transporter.

Materials storage and outfit materials machines are included in this investment plan, since a production increase is impossible when these machines are not sufficient.

The prices of the facilities are stated below. Prices are based on material costs and Cuban labour.

Table 45. Maximum section hot outfit concept investments

Location	Measurements	Price indication	Machines and facilities
Halls	88x25x18 12x14x8	€2 047 200	Both panel and section production; separate section conservation
Floors	2260 m2	€ 565 000	
Crane track 10t	172m	€81 000	
Crane track 60t	60m	€153 000	
Crane track 30t	28m	€42 000	
Panel machines		€100 000	4 small cranes (10t)
Section machines		€75 000	3 small cranes (10t)
Section and panel machines		€550 000	Big cranes (60t and 2x30t)
Slipway machines		€100 000	Section transporter (100t)
Other machines		€ 205 000	Materials storage crane and tracks; outfit production machines
Total		**€3993 200**	

Minimum of $720 000,- per year extra cashflow when building corresponding to the ideal DSGo shipyard on Cuba method. Corresponds with €545 500,-.

Internal Rate of Return over 15 years is 11%. The NPV is negative within 15 years. The investment is earned back within 8 years.

The section cold outfitting can be done outside. This does not require an investment, since there is sufficient area and old cranes available. How much this will increase the additional cash flow is not certain because of possible weather delays further in the process.

11.3.3 Maximum section outfit concept

This concept is the most productive, but requires the biggest investment. Concrete floors, halls and crane tracks are required. The slipway and outfitting quay transport and production machines are already there. This concept is calculated with one heavy crane for transporting light transport part packages, instead of three forklifts and a forklift lane, since one crane is cheaper than a wider hall and the forklifts.

A floor of 2631 m2 has to be constructed. A hall of (88x28x18) and a separate section conservation and outfitting hall is to be constructed. Separate section conservation is required for the same reasons as concept 2. Separate cold outfitting facilities are required because only a small production crane is required, since the section does not have to be turned. Both processes are considered to take place in one hall of (34x13x8). Separation of paint and cold outfitting processes is an operational problem. This can be done by a screen or a wall etc.

Materials storage and outfit materials machines are included in this investment plan, since a production increase is impossible when these machines are not sufficient.

The prices of the facilities are stated below. Prices are based on material costs and Cuban labour.

Table 46. Maximum section outfit concept investments

Location	Measurements	Price indication	Machines and facilities
Hall	88x25x18 34x13x8	€ 2158 100	Both panel and section production; separate hall for section conservation and cold outfitting
Floors	2631 m2	€ 660 000	Concrete floors
Crane track 10t	210m	€ 95 000	
Crane track 60t	60m	€ 156 000	
Crane track 30t	28m	€ 42 000	
Panel machines		€ 100 000	4 small cranes (10t)
Section machines		€ 125 000	4 small cranes (10t) + 1 for cold outfitting
Section and panel machines		€ 550 000	Big cranes (2x30t and 60t)
Slipway machines		€ 100 000	Section transporter (100t)
Other machines		€ 205 000	Materials storage crane and tracks; outfit production machines
Total		**€ 4191 100**	

Minimum of $895 000,- per year extra cashflow. Corresponds with €678 000,-.

Internal Rate of Return over 15 years is 14%. The NPV is positive within 12 years, and in 15 years it is €427 000,- . The investment in earned back within 7 years.

The production increase is sufficient (more than 50%) and the investment will pay off. However there are risks of investments regarding the political system in Cuba.

11.3.4 In-house steel part processing scenario

In this section the in-house steel part processing investment is analyzed for each concept.

Table 47. In-house steel part processing investments

Prefab hall	24 x 26 x 5 hall	€ 160 000	
Prefab floor	600m2	€150 000	
Crane track 10t	48m	€24 000	
Prefab transport		€ 100 000	4 small cranes (10t)
Machines prefab		€ 800 000	Plasma cutter, Plate press, Profile bender
Total		**€ 1 234 000**	

Annual cashflow consists of the difference between the costs of steel part processing in Cuba and the Dutch price. The steel part processing at Damex of a SPa4207 cost roughly €50 000,- and the Dutch costs are €100 000,- (incl. transport etc.) [J. Kossen]. The lifespan of a plasma cutting machine is 10 years.

Currently investing in in-house steel part processing generates an additional cash flow of €150 000,- per year. Given the current situation an investment in new machines and facilities does not pay off: an internal rate of return of 3%. However, when production is increased in accordance to the previously showed concepts the rate of return will improve.

- Cheap concept: IRR is 12%; NPV is €8484,-. This will not be a good investment.
- Maximum section hot outfit concept: IRR is 14%; NPV is € 152 500,-. This investment is profitable.
- Maximum section outfit concept: IRR is 16%; NPV is € 220 000,- This investment is profitable.

The investment will pay off when production is increased by (coincidantally) 46% or more.

11.3.5 Conclusion

To show which investment is best according to the targets and constraints given in chapter 1, the results are shown in table 48.

Table 48. Concepts and targets comparison

Targets and concepts	Concept 1: Cheap	Concept 2: Maximum section hot oufit	Concept 3: Maximum section oufit
Prod. Incr. +50%	+46,6%	+63,6%	+71,6%
IRR 12% (15 yr)	43%	11%	14%
NPV positive (15 yr)	€1880 000	Negative	€430 000
Investment size	**€ 1280 000**	**€3993 200**	**€ 4191 100**

Extra: In-house steel part processing	Yes	Yes	Yes

These number show that considering profitability concept 1 is by far the best, however this concept does not meet the target of a production increase of 50%. Concept 2 meets no targets but in-house steel part processing is sufficiently profitable for this concept. Concept 3 meets all targets but is less profitable than concept 1, since the investment is higher. But since all the targets are achieved, under the current assumptions, concept 3 is chosen as the best concept.

There has to be made a trade-off between the one with the highest internal rate of return or the most productive. This is a strategic choice that has to be made by the company.

11.4 Sensitivity analysis

Many things are assumed in this research, which means the results are not as reliable as they could be if more data was available. However there are some essential figures that contribute greatly to the results and are assumed. Therefore the sensitivity is tested. This is the case for the division of the hour tariff and the financing interest rate.

11.4.1 Indirect man-hour costs

The direct man-hour tariff is established as $3,- per hour, while the indirect component is established as $9,-. When the new investments are implemented, energy costs can increase. The sensitivity is tested when the indirect costs are increased by 10% and 20%. This corresponds with an increase of energy cost of roughly 100% and 200% (see chapter 1).

Indirect costs sensitivity	Cash flow total ($)	Difference ($)
Current indirect costs	895 626	0
+10% indirect costs	850 746	-44 879
+20% indirect costs	805 867	-89 759

This change means that the increase of energy costs decreases the profitability. A 10% increase in indirect costs, which roughly correspond with doubling of energy costs, reduces the IRR of 14% to 13%. This is still within the target limits. When energy costs triple, the IRR will be 11%.

11.4.2 Financing interest rate

The financing interest rate is established at 7%. Tested is if there is much difference when the interest rate is increased by 1% and 2% and decreased 1% percentage points (pp) compared to the current concept costs with constant ship price.

Financing costs sensitivity	Cash flow total ($)	Difference ($)
-1% pp interest rate	927 015	+31 388
Current interest rate	895 626	0,0
+1% pp interest rate	803 911	-91 715

+2% pp interest rate	692 228	-203 398

This analysis shows that an interest rate increase, decreases the additional cash flow. A 6% interest rate will increase the IRR to 15%. Since an interest rate decrease is very unlikely (central bank interest rates are at the lowest level ever) this is not a good prospect. At a 1% pp increase of interest rate the IRR becomes 11%. A 2% pp increase will reduce IRR to a mere 8%.

However, it is unlikely that when rates hike, they will not be calculated into the sales price. Therefore a 2% pp increase is very unlikely.

11.5 Optimal Damex layout

The best concept is chosen and all investment parameters are calculated. In this section a layout is chosen. The new layout must correspond with the required areas, must fit in the available area and must follow the guidelines of minimum transport and motion of products. Production of ships must go on and has to be taken into account.

Minimum transport and motion of products generally means a long continuous hall with successive sub-processes. A maximum hall width of two of the biggest main panels is used for cost reasons. When the building is wider, it will be more expensive, as well as the cranes (bigger span).

A material park of 12m wide and 50m long is the first thing that has to be set up. The panel and section production hall is 88m long and 25m wide. The separate section conservation and cold outfitting hall must be 34m wide and 13m long. The steel part processing hall must be at least 600 m2 and is placed between the material park and the panel and section building hall.

Theoretically there are two layout possibilities. One is on the current container park and section building location, and the other on the current material park. Both are presented and analyzed in this chapter.

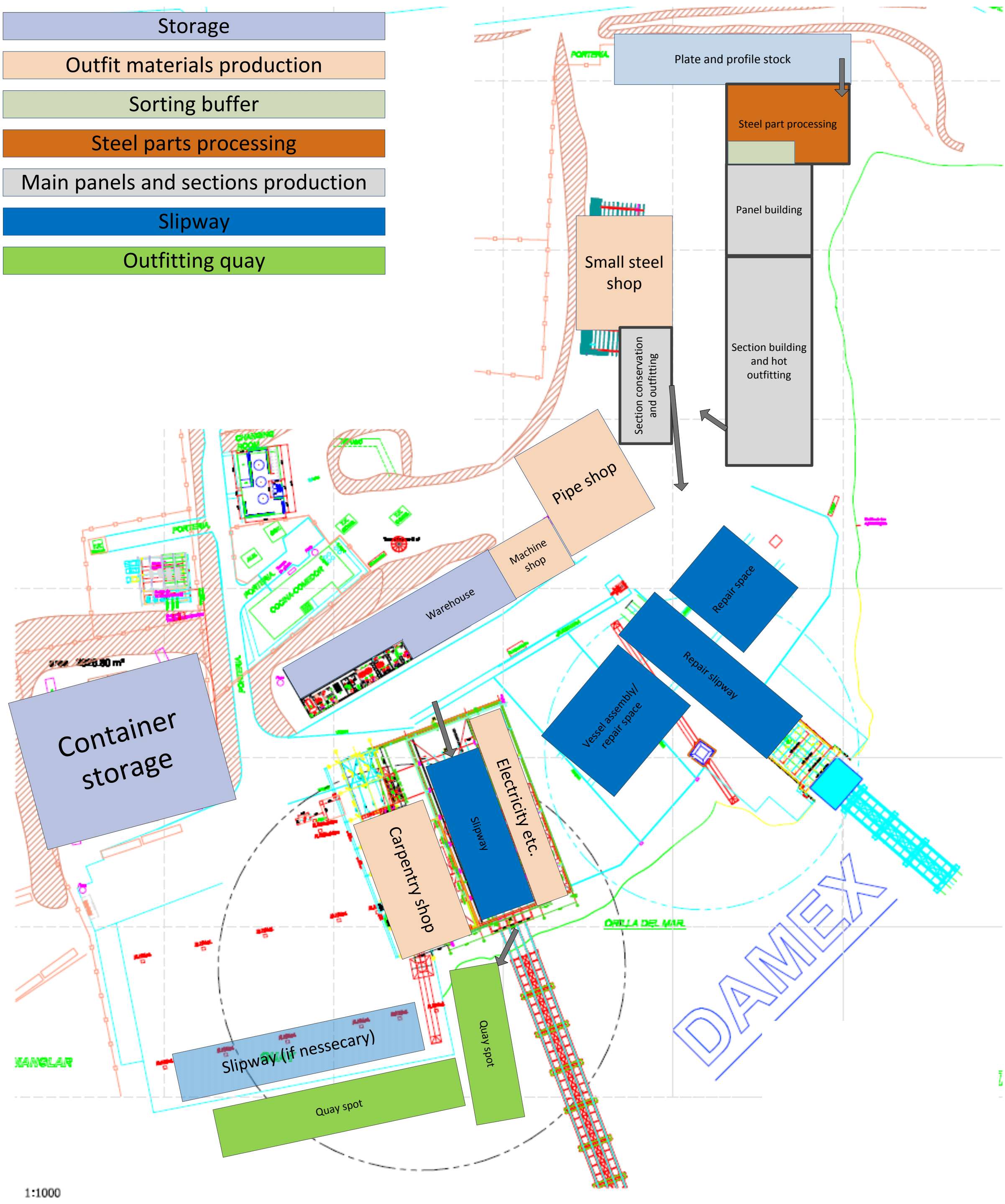

Figure 64. Layout of new facilities at location of current material park

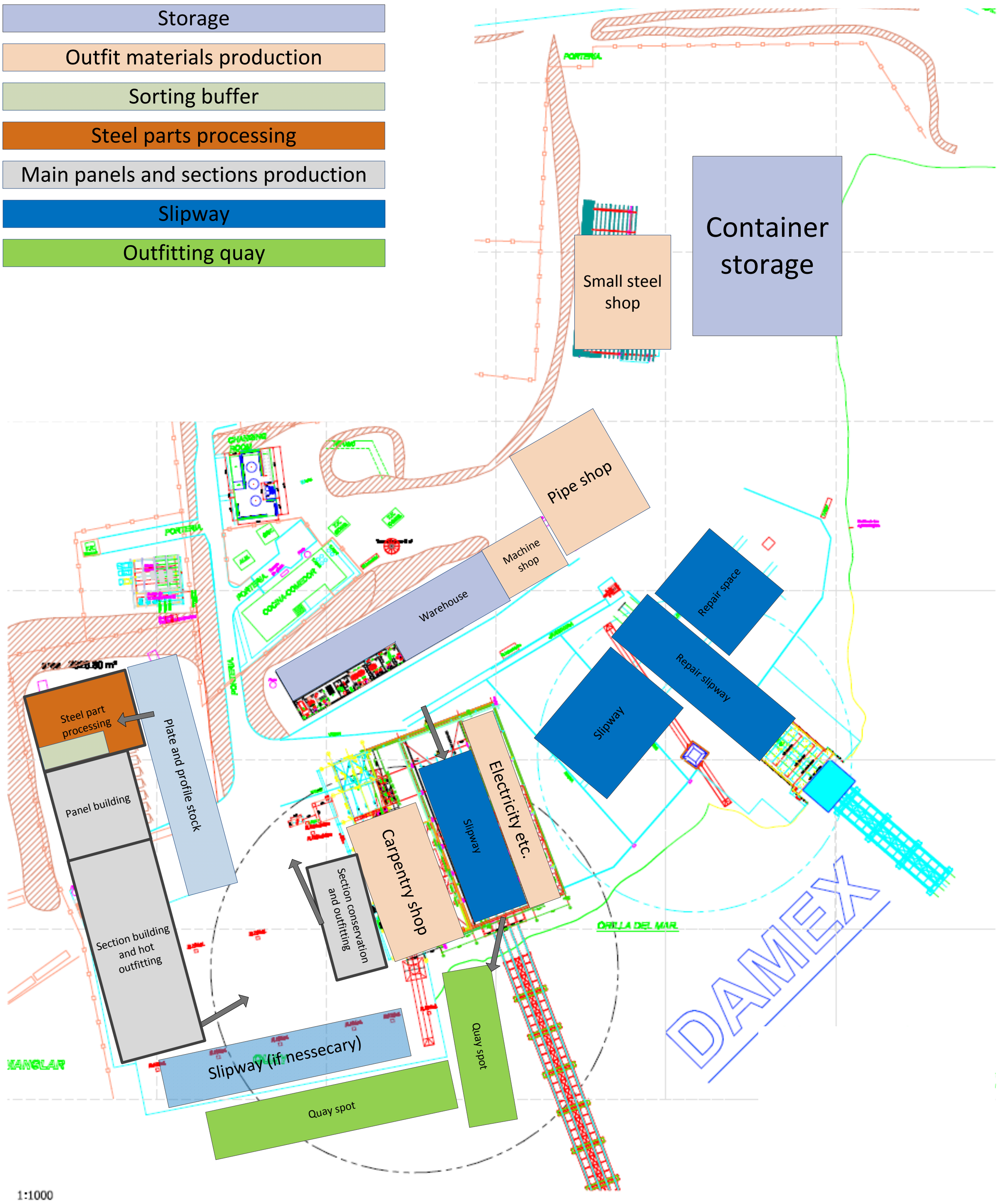

Figure 65. Layout of new facilities at location of current section building area

Both versions have their pros and cons. The first version has a better flow of materials and less motion (turning of products). The second layout has less section transport distance to cover. However a major issue is that this second version is located on the current section building location. Therefore Damex is unable to continue its shipbuilding activities during construction of the new facilities.

Therefore the best layout is layout number 1 at the location of the current material park.

11.6 Investment plan

The investment does not have to be implemented in one go. The new facilities can be built in phases.

This investment plan assumes that all existing plans for Damex are completed. These are: improving power grid; extending the warehouse; new workshop next to the warehouse; placing old DSGo maintenance building next to new carpentry shop. The outfit material production processes are arranged in these new and existing buildings as stated in the layout. Also the door at the covered slipway must have been increased. Sections must be able to get onto the slipway.

11.6.1 Storage of steel materials

Since the new facilities will be located at the location of the current material park, first a new and better material park has to be constructed to ensure that production can go on.

11.6.2 Panel and section building hall

When the storage of steel materials is operational, the panel and section building hall is constructed. The steel part processing hall is not yet necessary, since the shipyard's production has not been increased yet.

11.6.3 Section conservation and cold outfitting hall

When the panel and section building hall is finished, pre-outfitted sections can be moved to the next process. This is section conservation, and after that section cold outfitting, which are performed in a separate hall. This hall is the next in line to be built.

11.6.4 Steel part processing

When the section conservation and cold outfitting hall is finished, the production can be increased. After that it is financially feasible to construct a steel part processing hall and place the machines.

11.6.5 More production increase

When production is to be increased more, at the old section building location a new hall can be constructed. When the workforce is extended, the new building can enable the production increase of 200%.

12 CONCLUSIONS, DISCUSSION AND RECOMMENDATIONS

Damen Shipyard Group (DSG) is a shipbuilding group that builds a large variety of ships at a great number of shipyards. These shipyards are strategically located around the world in a various countries. One of the foreign DSG shipyards is Damex Shipbuilding and Engineering in Santiago de Cuba (Damex). Damex rents property, workers and equipment from Astor, a Cuban state company. This construction contains the risk that the Cuban government can nationalize the company, and DSG loses its investments.

At Damex the following problems are determined: the cost price per ship is too high, the production capacity of the shipyard is too low and the throughput time of the ships is too long.

These problems are translated in the following targets:

- Damex annual production capacity must be increased by at least 50%
- For investments the annual internal rate of return must have a minimum of 12% over 15 years
- Net present value of the investment, with an annual discount rate of 12%, must become positive over 15 years

The targets are limited by the following constraints:

- The capacity is calculated by using the current product portfolio
- The number of employees (and thus annual man-hours) is constant
- A lower investment is preferred in this research

Investigated is whether it is possible and what it takes to increase production by 200% and whether steel part processing is to be done in-house or outsourced in the Netherlands.

The main research question is therefore: What is an optimal yard layout regarding cost efficiency for Damex Shipbuilding and Engineering, Santiago de Cuba?

To answer this question, first Damex is modeled into a sytem according to the Delft Systems Approach. The used system consists of an input material and output products flow; and the process and its required resources. Since the ship assembly process is the main value adding process of Damex and its productivity can be improved, this process is analyzed, modeled and improved in this research.

Ship assembly productivity can be improved by:

- Having the ship assembly processes organized in such a way that there is as little non value adding time as possible
- Intermediate products are as advanced as possible before ship erection at the slipway
- Mechanization of ship assembly processes
- Workers are skilled and specialized in the assembly of certain (intermediate) products

Of all these different properties several production method scenarios are made. These scenarios produce the three different ships. The scenarios that meet the production increase targets are identified and molded into concepts. The required investments of the concepts that meet the production increase targets are assessed for the internal rate of return and net present value targets. Of the concepts that meet all targets, the cheapest is selected in accordance to the design constraints.

12.1.1 Conclusions

Under the current assumptions, the concept that meets all targets and requirements is the maximum section outfit concept. In this concept panel building, section building, maximum outfitting and section conservation are done during section building inside a hall, by using sufficient cranes and transport machines. These outfitted and painted sections are transported to the slipway hall by a section transporter. There the ship is erected, further outfitted and launched. After the launch it is finished at the outfitting quay.

This concept requires an investment of €4 191 100,- and causes a production increase of 71,6%. The internal rate of return over 15 years is 14%, and the net present value is €430 000.

In-house steel parts processing is a good investment when the optimal concept is implemented. The in-house steel parts processing does not increase production, but costs are reduced. In-house steel parts processing requires an investment of €1 234 0000,-. Internal rate of return is 14% and the net present value is €220 000,-.

A production increase of 200% is possible, but not when the current workforce is constant. When this increase is to be done, the workforce must be increased by 71,6%. There is sufficient area at the shipyard, but one large, or multiple new smaller halls have to be built.

12.1.2 Discussion

Considering the design targets the best concept is chosen in this conclusion. However, the cheap concept investments are low and profitability is much higher, but production increase is too low. It can be argued that this concept is more tempting than the optimal concept considering the Cuban investment risks. But this is for the company to decide.

Possible concepts like producing panels outside or section painting outside in order to reduce investments and reduce increased production capacity a little (until +50%), are considered unfeasible. Producing panels outside or painting sections outside causes unknown disruptions of the process, since the weather is unpredictable. Of course this happens in the current situation, but currently everything is disrupted because of the weather in an equal basis. Large intermediate buffers can be an option for this possible concept.

Outfitting of sections outside after fully hot outfitting and conservation during section building inside can be done, but weather conditions make this option less predictable. If these options are considered by the company, these have to be further investigated.

12.1.3 Recommendations

The biggest problem in this research was the amount of and quality of data. The product data of the SPa4207 ship was not complete. Also the direct and indirect components of the current man-hour tariff was unknown. More research is required for this.

Better data regarding cranes, specific production times and weather is desirable to have, but very hard to obtain at Damex. Damex does not register these specific hours. It is not certain whether DSGo can obtain these data economically, since they will have to be measured. Internships could be an option.

Data about investments are of course desirable to have but they are the least reliable, since they are determined by the market. A possibility could be to create a database of historical prices of past investments.

More research can be required about materials arrival and storage and outfit materials production processes to determine increased profitability when machines are replaced by more productive ones.

More research about the effect of partly inside and partly outside production can be useful to determine more options for investment analysis.

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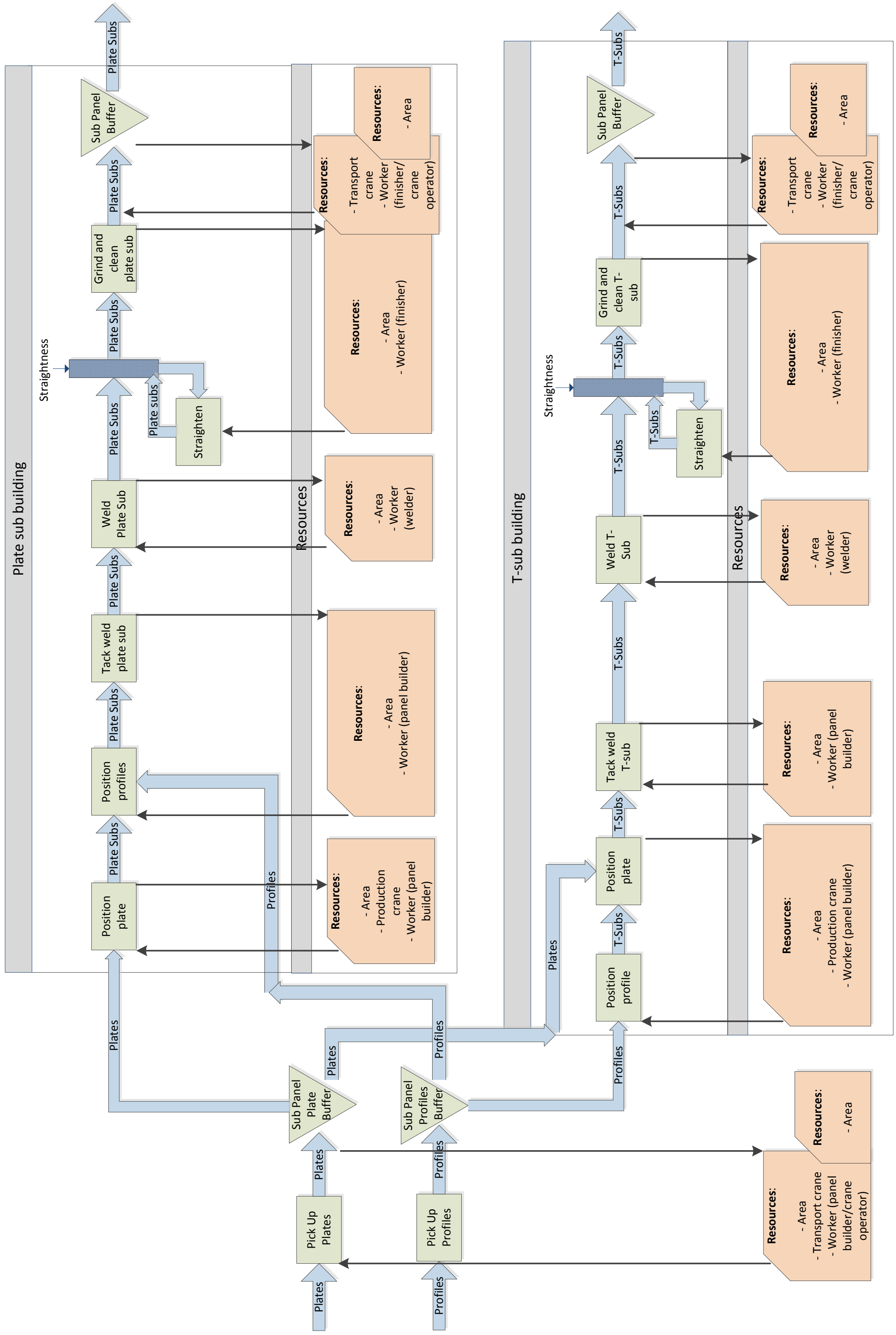
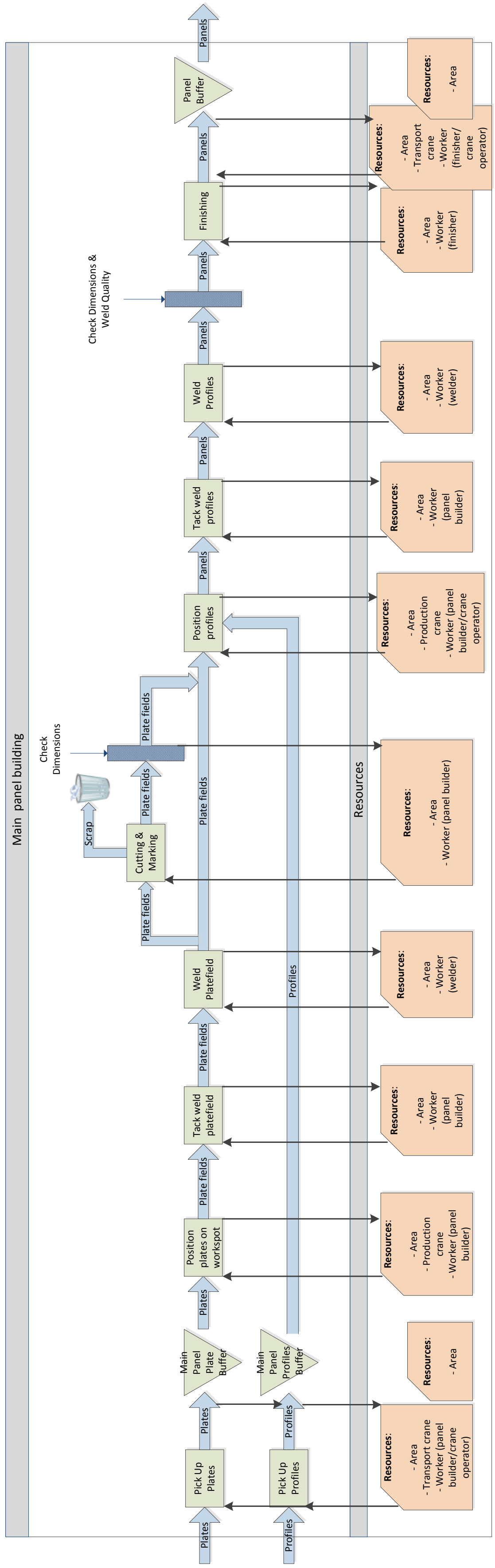
APPENDICES

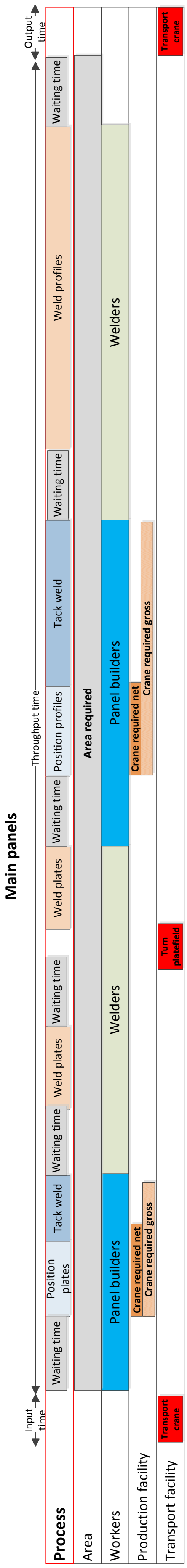
Appendix A: Panel building

Sub panel production process model



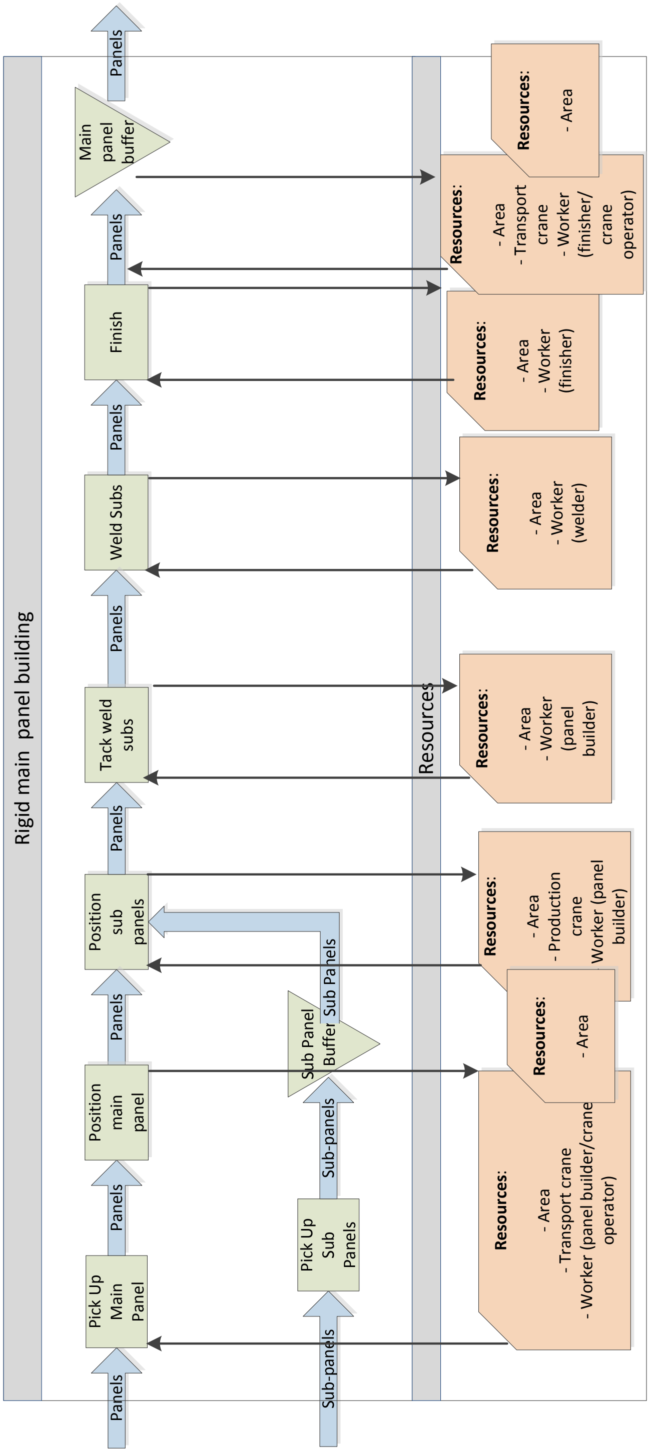
Main panel production process model





Main panels
Input time
Throughput time
Output time
Process
Area
Workers
Production facility
Transport facility
Waiting time
Position plates
Tack weld
Waiting time
Weld plates
Waiting time
Weld plates
Waiting time
Position profiles
Tack weld
Waiting time
Weld profiles
Waiting time
Area required
Panel builders
Welders
Panel builders
Welders
Crane required net
Crane required gross
Crane required net
Crane required gross
Transport crane
Turn platefield
Transport crane

Rigid main panel production process model



Calculations

In order to calculate the values the following equations are used:

$$A_{panel.prod} = A_{84\%panel} * WIP_{panel}$$

$$WIP_{panel} = \frac{n_{panel} * \bar{t}_{panel}}{2200}$$

For transport, input steel parts can be transported by light and heavy cranes. Light cranes transport individual plates and the profile pack for the panel. Heavy cranes transport comprises the turning of the plate-field, the output transport and possibly an input transport of packed input parts. The light variant (one small and a big crane) of the transport is:

$$n_{tr.light} = \frac{(n_{panel} + n_{plates}) * \bar{t}_{transport}}{2200 * 50\%}$$

$$n_{tr.heavy} = \frac{2 * n_{panel} * \bar{t}_{transport}}{2200 * 70\%}$$

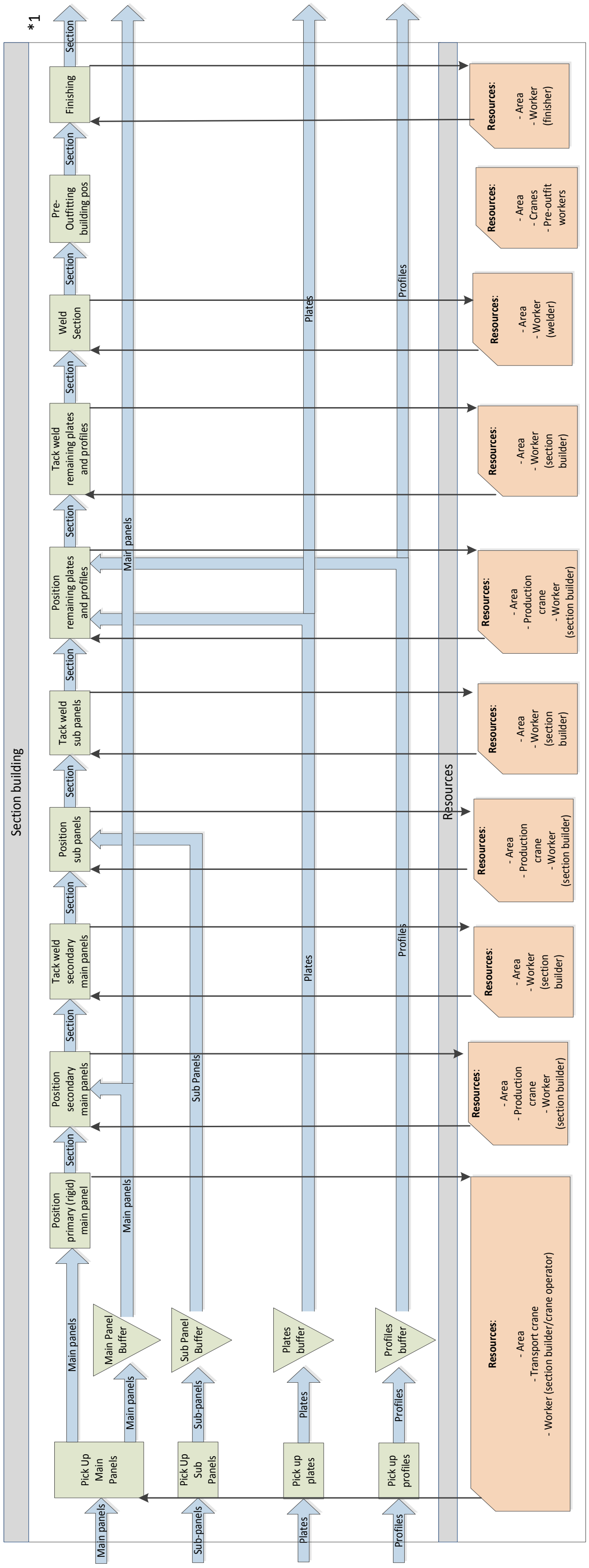
Since the light variant transports plates individually and the heavy variant per pack (per panel), the heavy variant has less transport moves. For the powerful variant the following equation is derived:

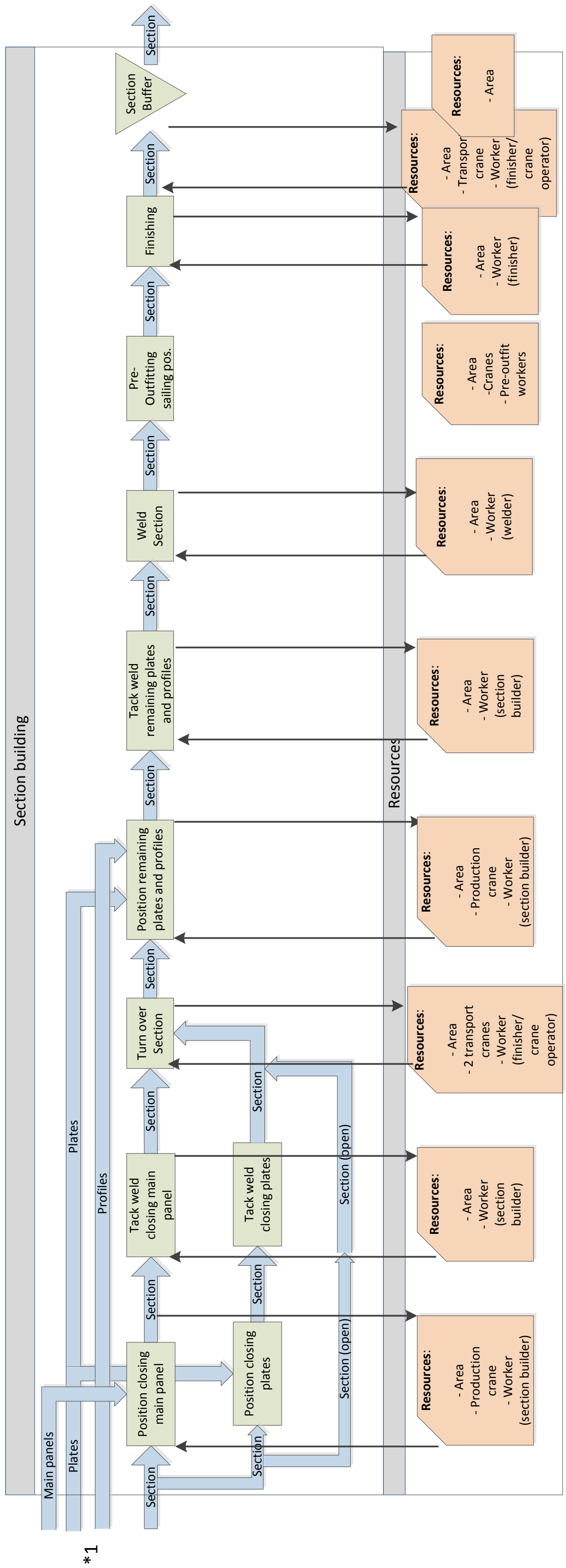
$$n_{tr.heavy} = \frac{4 * n_{panel} * \bar{t}_{transport}}{2200 * 70\%}$$

Man-hours are calculated by using hours/area as explained in chapter 5.

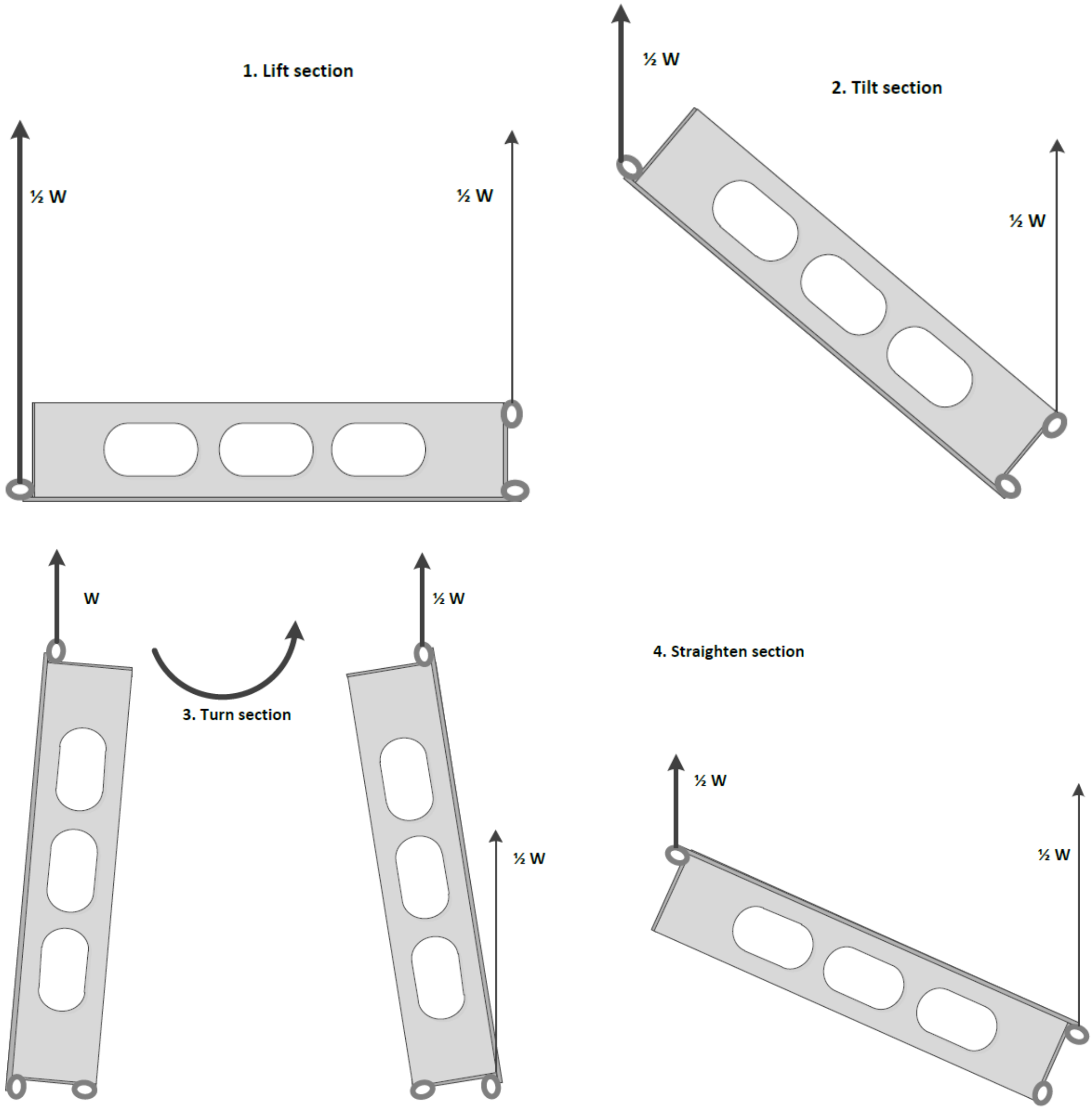
Appendix B: Section production

Section production process model




Section building
Resources
Main panels
Plates
Profiles
Plates
Section
Position closing main panel
Tack weld closing main panel
Turn over Section
Position remaining plates and profiles
Tack weld remaining plates and profiles
Weld Section
Pre-Outfitting sailing pos.
Finishing
Section Buffer
Position closing plates
Tack weld closing plates
Section (open)
Resources: - Area - Production crane - Worker (section builder)
Resources: - Area - Worker (section builder)
Resources: - Area - 2 transport cranes - Worker (finisher/ crane operator)
Resources: - Area - Production crane - Worker (section builder)
Resources: - Area - Worker (section builder)
Resources: - Area - Worker (welder)
Resources: - Area -Cranes - Pre-outfit workers
Resources: - Area - Worker (finisher)
Resources: - Area - Transport crane - Worker (finisher/ crane operator)
Resources: - Area
*1

Controlled turning of sections



The reason for a 60 tons and 30 tons crane is explained above

Calculations

Man-hours are calculated by using hours/ton as explained in chapter 5.

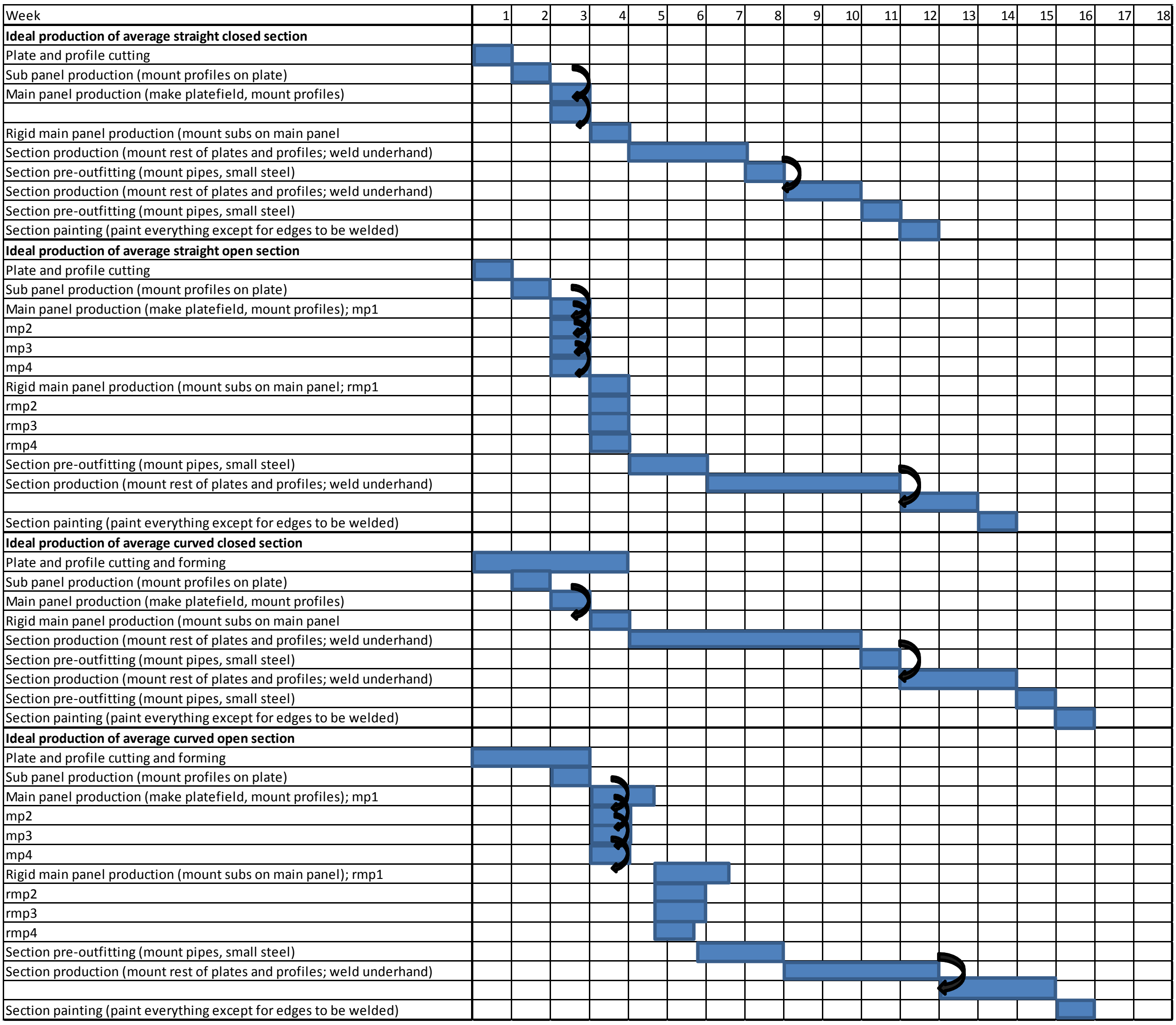
Area and cranes are calculated as explained in appendix A

Procedure from steel parts to section

There are 4 types of sections:

- Closed straight sections
- Closed curved sections
- Open straight sections
- Closed straight sections

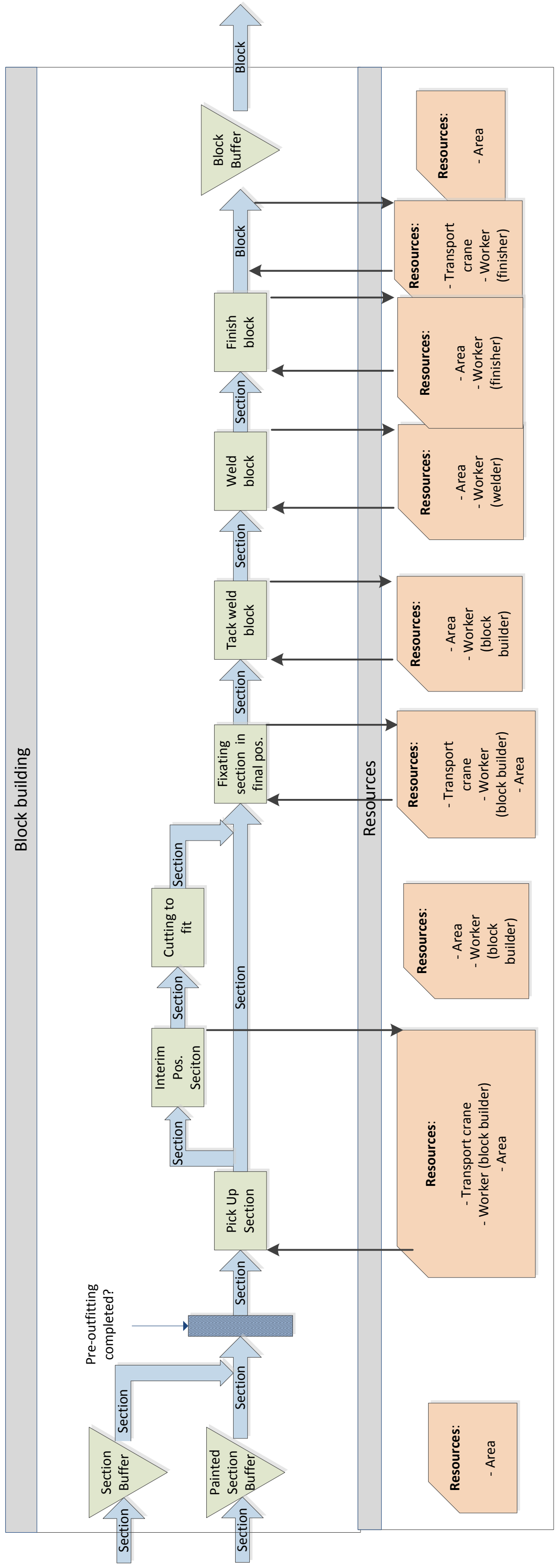
The procedure of the assembly of each sections is shown below (process times are not representative for Damex)



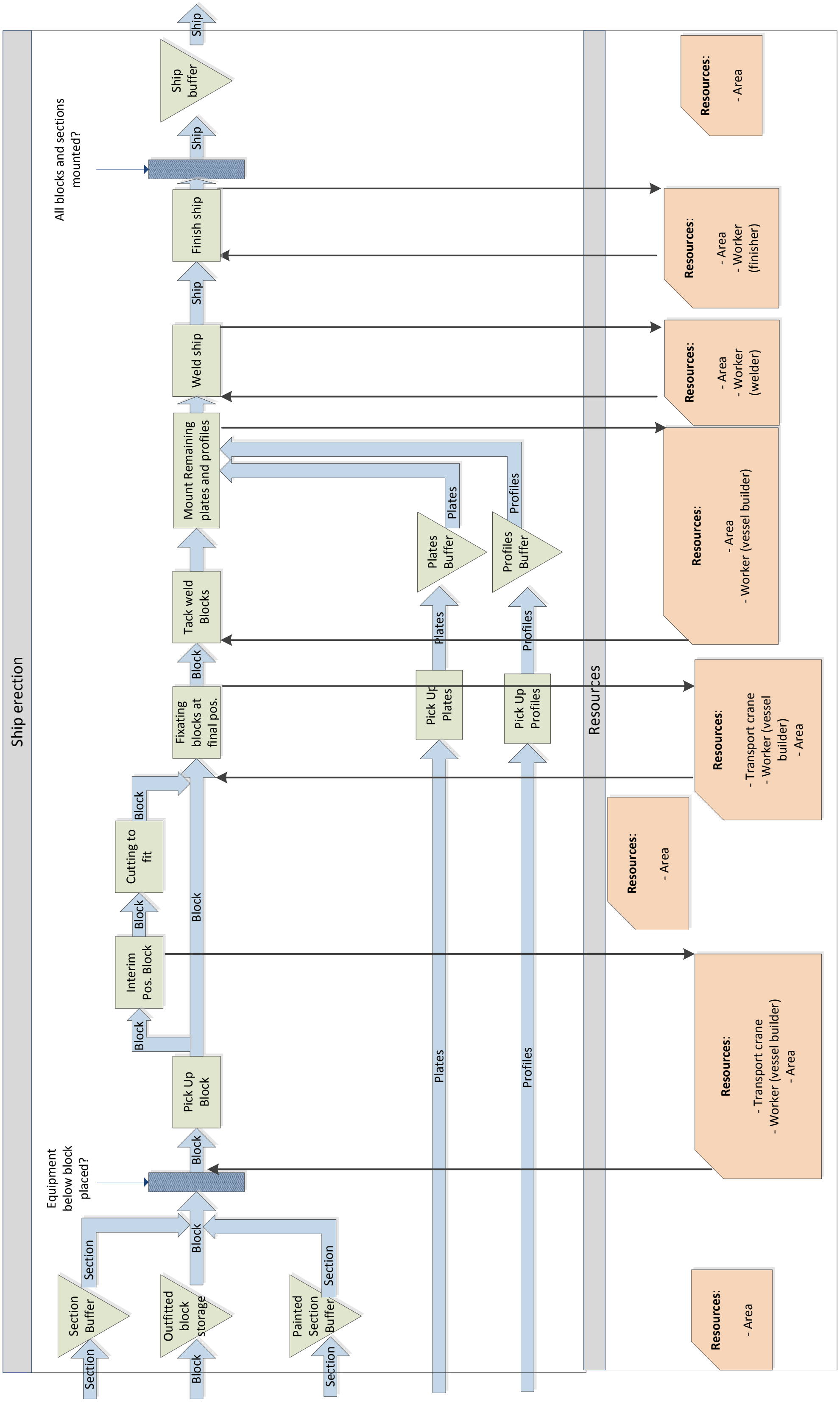
Currently the section building is planned according to the method above. By dividing this total section building process into intermediate product production processes, these processes are made more measurable by using Little's Law.

Appendix C: Block building and ship erection

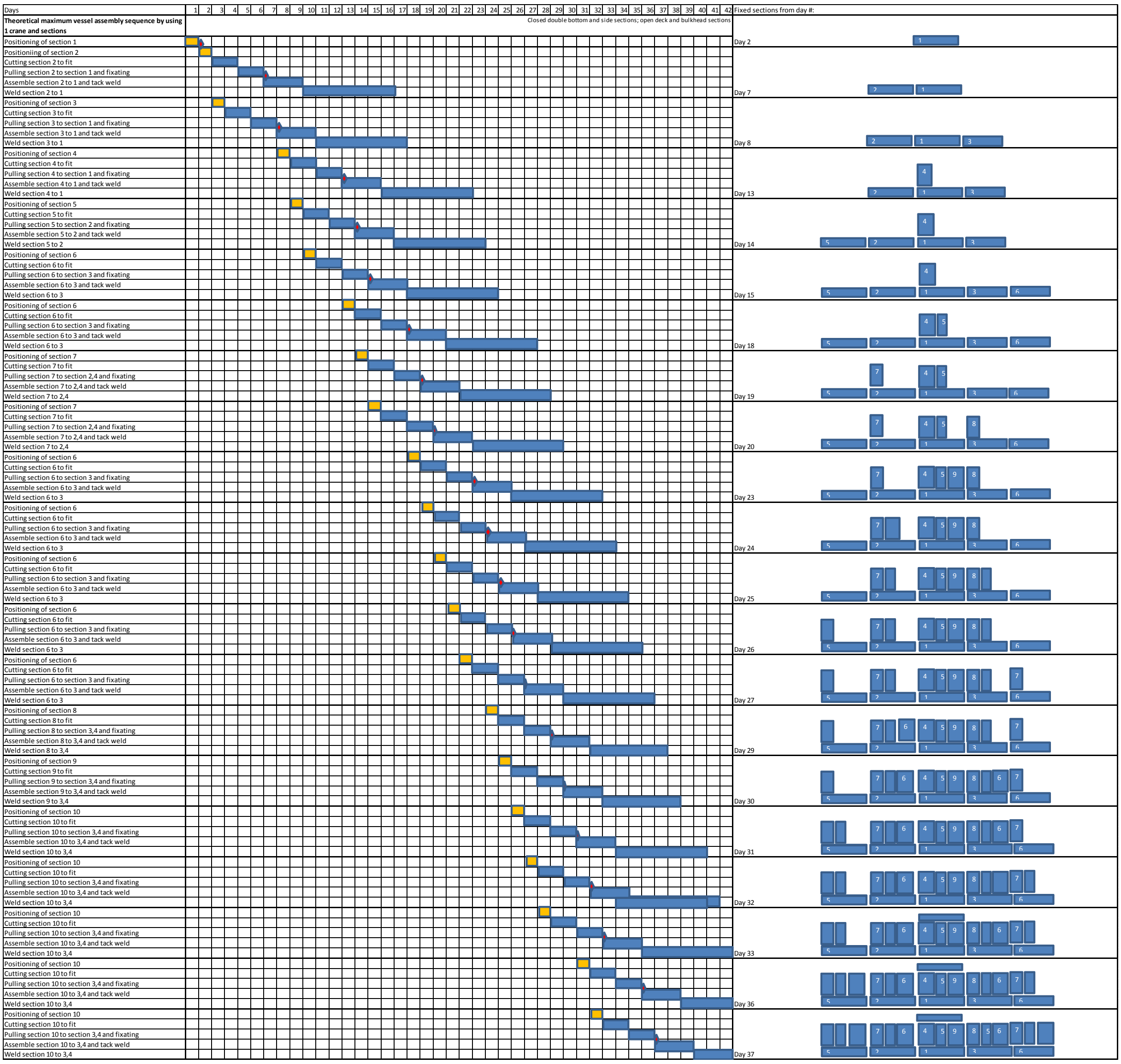
Process model block building



Process model ship erection



Ship erection by using sections



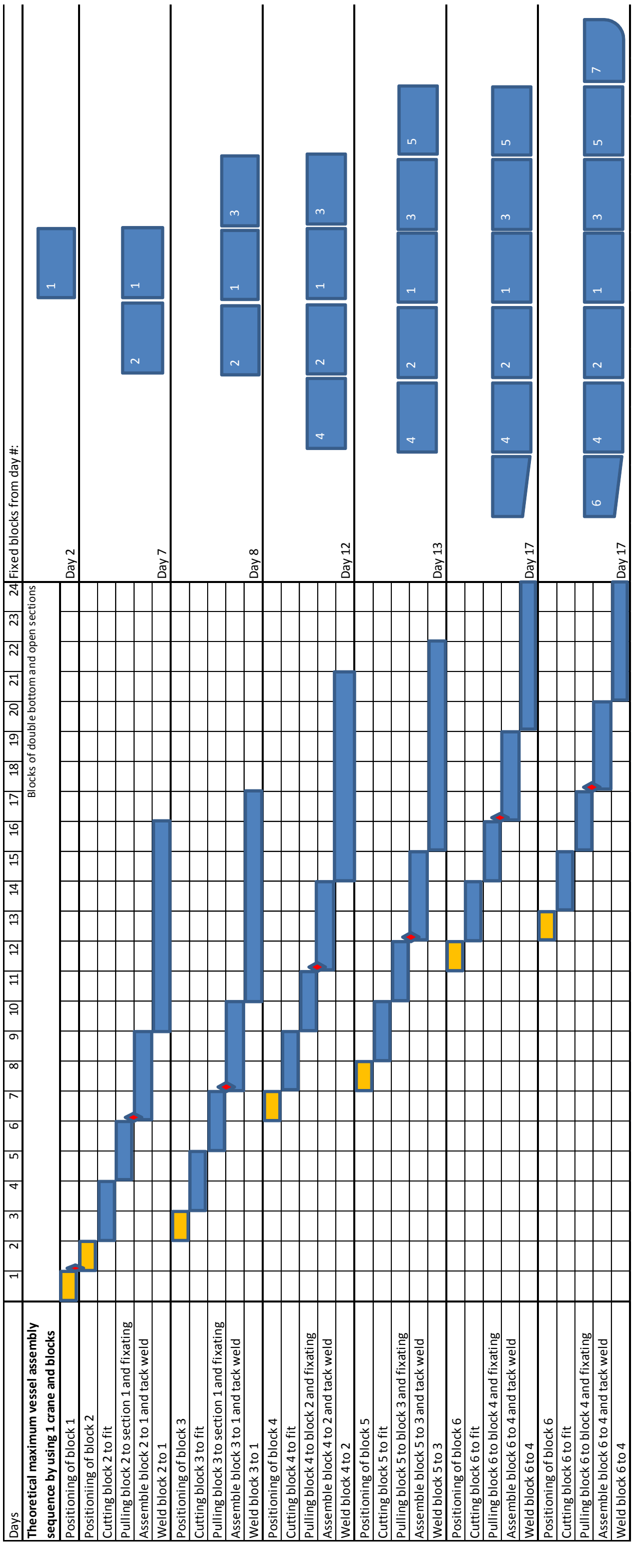
Almost every day a new section can be placed when there are several sections per block (3,625 for the SLa5612). As can be seen, ship erection by using sections goes pretty quick.

For 6 SLa5612, 174 sections have to be assembled to erect 6 ships. This is a total of 2658 tons. Assembly requires 5,79 hours (not man-hours) per ton. The average weight of a section is 15,27 tons. Therefore it takes 88,5 hours to assemble and weld one section (throughput time). It takes on average 44 hours (1 week) to fix a section. But sections can be assembled a lot faster, as shown above, because there are multiple sections per block, and 2 sides on a ship (when started somewhere in the middle). Only the final section takes the full duration of assembly. Therefore the throughput time is :

$$T_{er.ship} = \frac{t_{fix} * \#_{sec}}{2 * (\frac{\#_{sec}}{\#_{bl}})} + \#_{ships} * t_{ass} = \frac{44 * 174}{2 * 3{,}625} + 6 * 88{,}5 = 1587\ hours$$

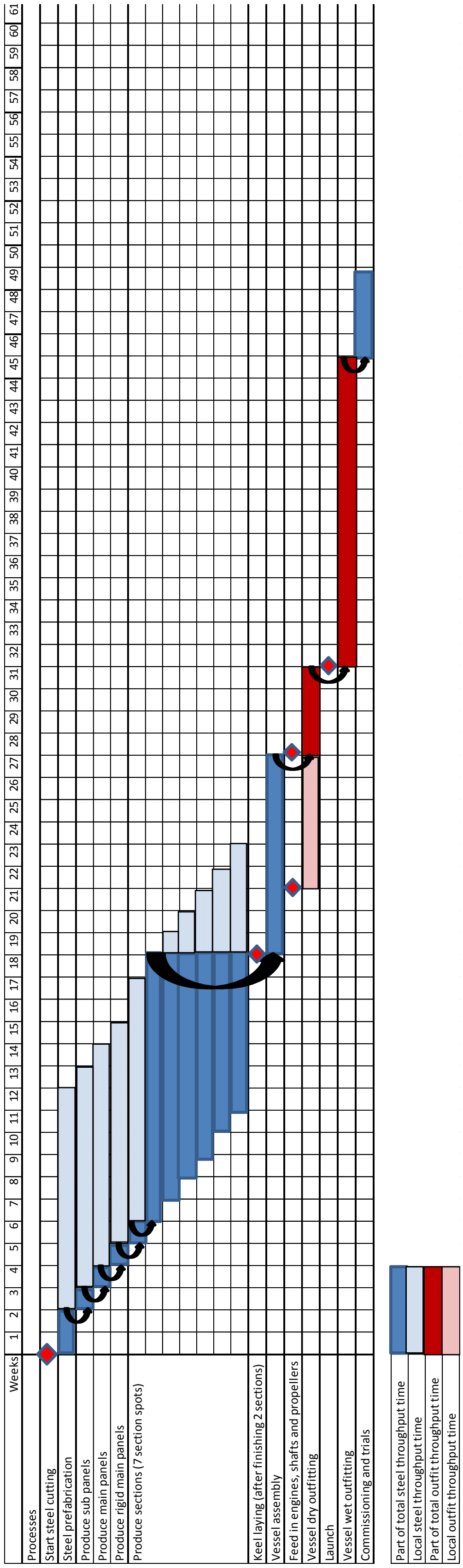
This means that for ship erection only one slipway is required. However, some outfitting and painting is also required at the slipway. But since there are 2, and possibly 3 slipways, this is no problem.

Ship erection by using blocks

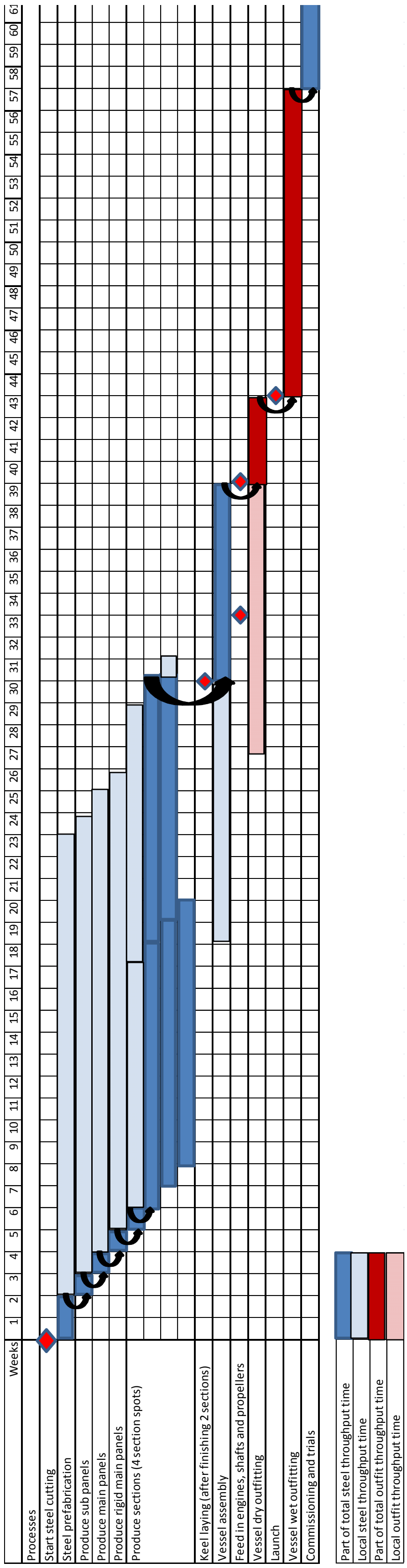


Two blocks can be places per week (front and aft) except for the first week, then 3 can be placed. Ship erection by using blocks goes faster than by using section. However, 2 blocks per week have to be ready for erection, which is a lot concerning Damex.

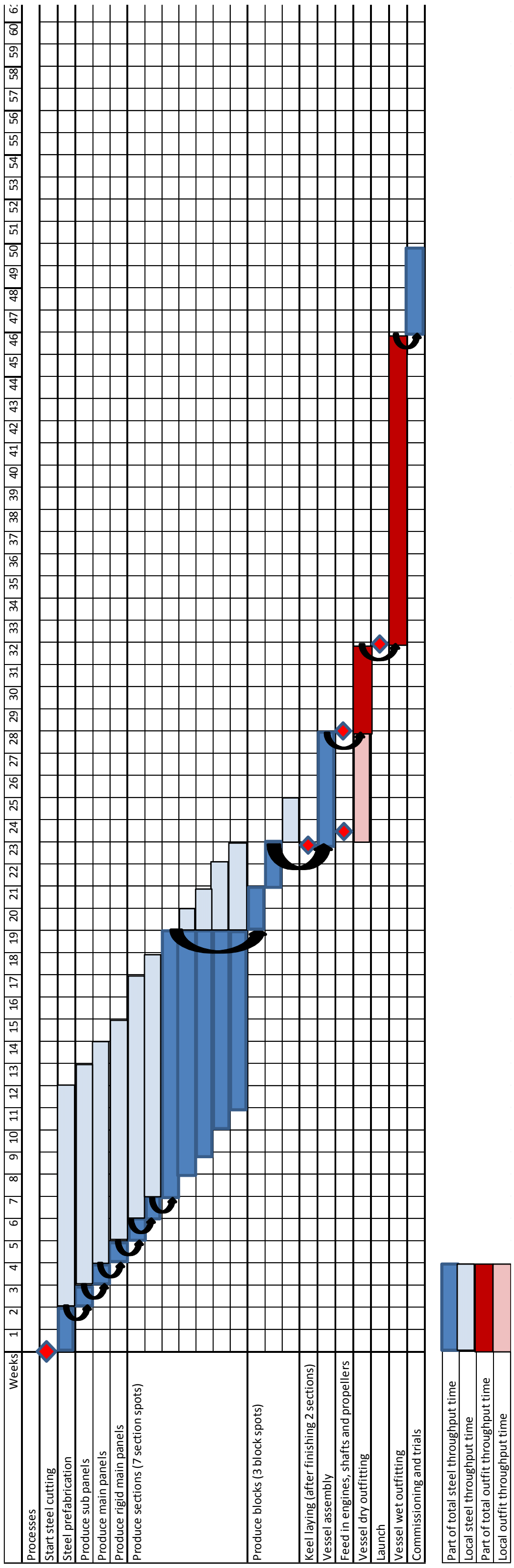
The total time can be calculated by the sum of all assembly (fixing fulcrums) times, divided over the number of sections per block, plus the total assembly, tack weld and weld time.



Main building schedule for STu2208. Enough sections are assembled for short ship erection process.



When there are too few sections to erect the ship at once, because there are too few building spots, the total throughput time is longer and the slipway is occupied



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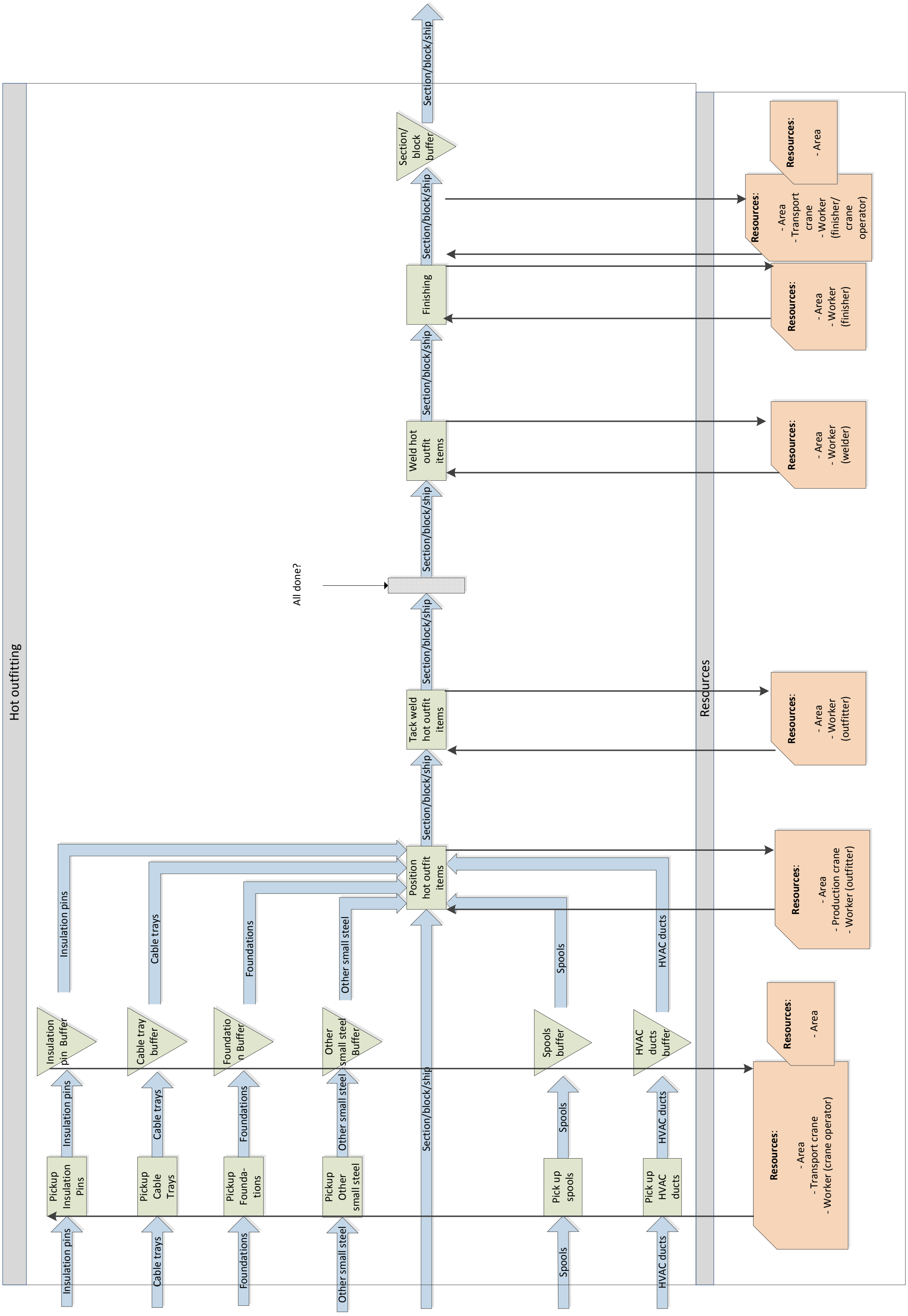
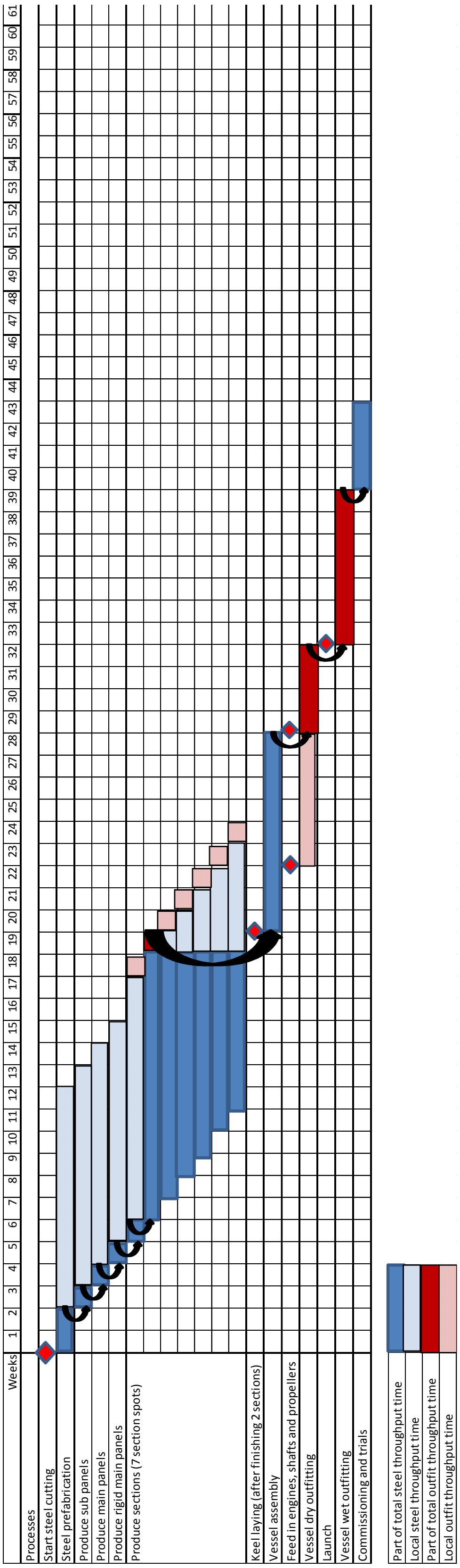
When blocks are built, but section building is not increased sufficiently, total throughput time is not affected. Block building is basically ship erection, but not on the slipway.

Appendix D: Hot outfitting

Hot outfitting process model





When hot outfitting is applied during section building, the local throughput time per section is increased, in this example by one week. The ship erection time is as long as the old version, but outfitting at the slipway and quay are reduced, because the outfit is already applied during section building.

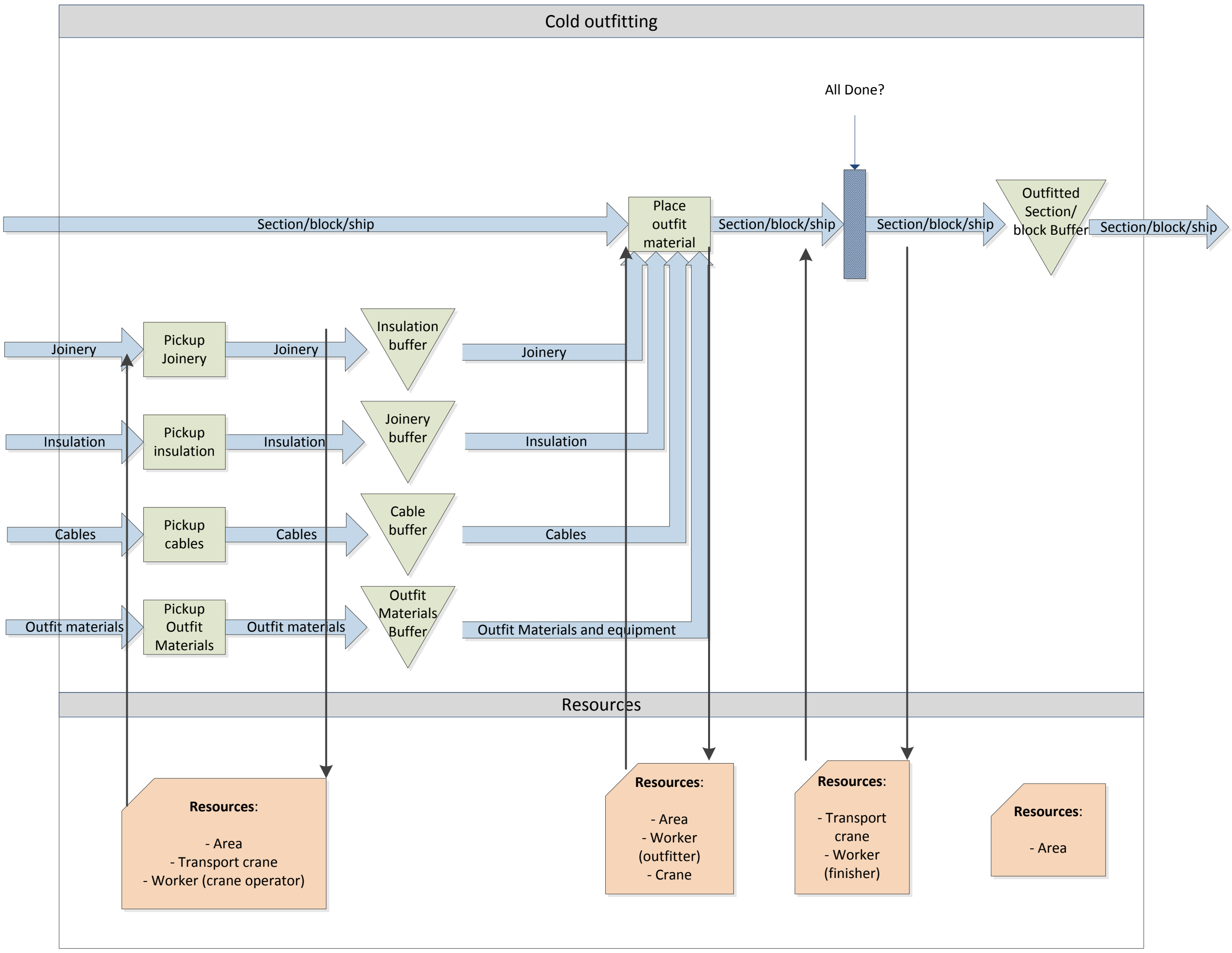
Calculation of average throughput time per item or m2

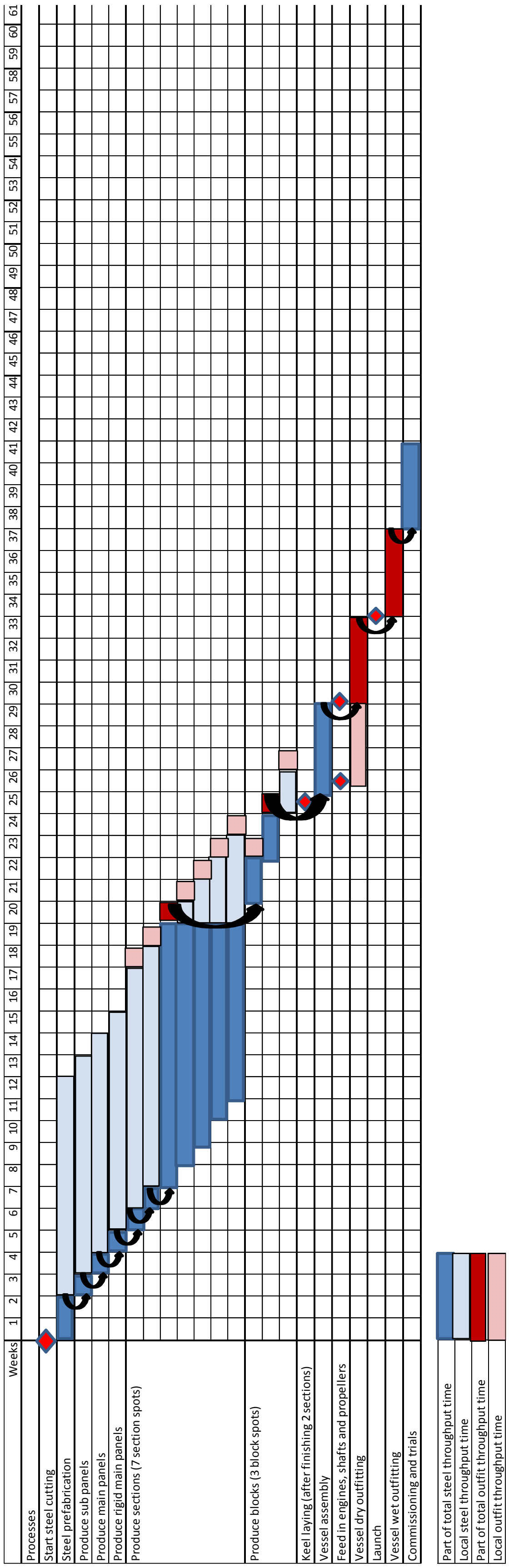
Below the obtained throughput data about several hot outfit parts is given.

Hot outfit	**Section hot outfitting**		**Slipway ship outfitting**		**Quay ship outfitting**	
	Hours	Fitters/part	Hours	Fitters/part	Hours	Fitters/part
Piping	4	2	10	3	10	4
Cable trays	3		7,5		7,5	
HVAC ducts	3		7,5		7,5	
Foundations and small tanks	3		7,5		7,5	
Other small steel	1		3		3	
Insulation pins (m2)	0,33		1		1	

Appendix E: Cold outfitting

Cold outfitting process model





When sections (or blocks in this example) are completely fitted with hot outfit and after that painted, cold outfit can be installed. This further reduces the outfitting time at the slipway and quay.

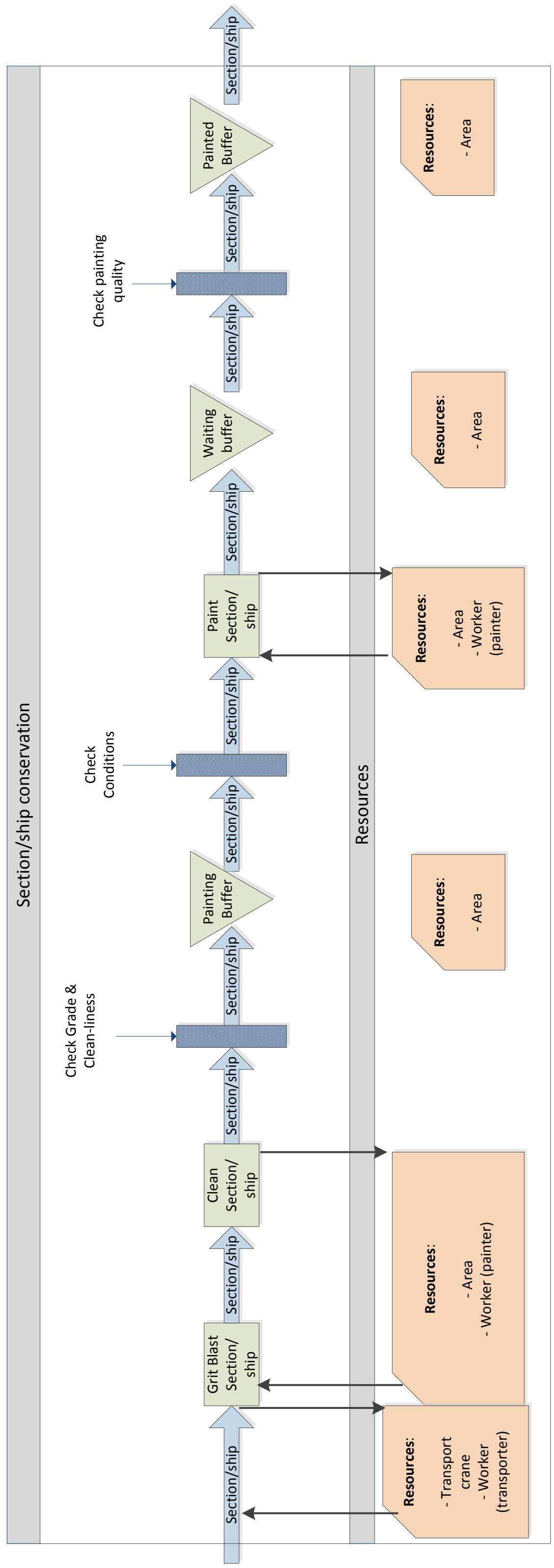
Calculation of average throughput time per item or m2

Below the obtained throughput data about several hot outfit parts is given.

Cold outfit	Section cold outfitting		Slipway ship outfitting		Quay ship outfitting	
	Hours	Fitters/part	Hours	Fitters/part	Hours	Fitters/part
Cables	2	3	4	3	5	4
Insulation (m2)	1,25		1,56		1,56	
Joinery (m2)	1		1,25		1,25	
Heavy equipment	8		11		17,6	
Small equipments	1		2		3	

Appendix F: Ship conservation

Conservation process model



Appendix G: Financial analysis

Direct man-hour %, throughput time % and indirect costs % compared to as-is.

	Direct man-hour %	Throughput time %	Indirect costs
As-is	100	100	100
Cheap	68,6	84	68,6
Sec. H. o.f.	61,6	94	61,6
Sec. C. o.f.	58,5	84	58,5

Influencable cost

Costs per ship ($)	**Direct man-hour costs**			**Materials financing costs**			**Distributed indirect costs**		
	SLa5612	SPa4207	STu2208	SLa5612	SPa4207	STu2208	SLa5612	SPa4207	STu2208
As-is	319155	236559	119679	436207	475718	111891	224398	149599	89759
Cheap	219080	162383	82152	368065	401404	94412	153039	102026	61215
Sec. H. o.f.	196593	145715	73720	408689	445708	104833	137206	91471	54882
Sec. C. o.f.	187163	138726	70184	368065	401404	94412	130802	87201	52321

Appendix H: Investment analysis

Net present value calculations and internal rate of return calculations

Cheap concept

Cheap concept		
Year	Cash flow	Discounted cash flow
0	-€ 1.280.000	-€ 1.280.000
1	€ 464.044	€ 414.325
2	€ 464.044	€ 369.933
3	€ 464.044	€ 330.297
4	€ 464.044	€ 294.908
5	€ 464.044	€ 263.311
6	€ 464.044	€ 235.099
7	€ 464.044	€ 209.910
8	€ 464.044	€ 187.420
9	€ 464.044	€ 167.339
10	€ 464.044	€ 149.410
11	€ 464.044	€ 133.402
12	€ 464.044	€ 119.109
13	€ 464.044	€ 106.347
14	€ 464.044	€ 94.953
15	€ 464.044	€ 84.779
	Discount rate	1,12
	IRR	36%
	NPV	€ 1.880.541

Section hot outfit concept

Section hot outfit concept				
	Forklifts		Crane transport	
Year	Cash flow	Discounted cash flow	Cash flow	Discounted cash flow
0	-€ 4.232.800	-€ 4.232.800	-€ 3.993.200	-€ 3.993.200
1	€ 545.507	€ 487.060	€ 545.507	€ 487.060
2	€ 545.507	€ 434.875	€ 545.507	€ 434.875
3	€ 545.507	€ 388.281	€ 545.507	€ 388.281
4	€ 545.507	€ 346.680	€ 545.507	€ 346.680
5	€ 545.507	€ 309.535	€ 545.507	€ 309.535
6	€ 545.507	€ 276.371	€ 545.507	€ 276.371
7	€ 545.507	€ 246.760	€ 545.507	€ 246.760
8	€ 545.507	€ 220.321	€ 545.507	€ 220.321
9	€ 545.507	€ 196.715	€ 545.507	€ 196.715
10	€ 545.507	€ 175.639	€ 545.507	€ 175.639
11	€ 545.507	€ 156.820	€ 545.507	€ 156.820
12	€ 545.507	€ 140.018	€ 545.507	€ 140.018
13	€ 545.507	€ 125.016	€ 545.507	€ 125.016
14	€ 545.507	€ 111.622	€ 545.507	€ 111.622
15	€ 545.507	€ 99.662	€ 545.507	€ 99.662

	Discount rate	1,12		
	IRR	10%		11%
	NPV	€ -517.426		€ -277.826

Maximum section outfit concept

Section outfit concept				
	Forklifts		Crane transport	
Year	Cash flow	Discounted cash flow	Cash flow	Discounted cash flow
0	€ -4.680.000	€ -4.680.000	€ -4.191.100	€ -4.191.100
1	€ 678.504	€ 605.807	€ 678.504	€ 605.807
2	€ 678.504	€ 540.899	€ 678.504	€ 540.899
3	€ 678.504	€ 482.946	€ 678.504	€ 482.946
4	€ 678.504	€ 431.202	€ 678.504	€ 431.202
5	€ 678.504	€ 385.001	€ 678.504	€ 385.001
6	€ 678.504	€ 343.751	€ 678.504	€ 343.751
7	€ 678.504	€ 306.921	€ 678.504	€ 306.921
8	€ 678.504	€ 274.036	€ 678.504	€ 274.036
9	€ 678.504	€ 244.675	€ 678.504	€ 244.675
10	€ 678.504	€ 218.460	€ 678.504	€ 218.460
11	€ 678.504	€ 195.054	€ 678.504	€ 195.054
12	€ 678.504	€ 174.155	€ 678.504	€ 174.155
13	€ 678.504	€ 155.496	€ 678.504	€ 155.496
14	€ 678.504	€ 138.835	€ 678.504	€ 138.835
15	€ 678.504	€ 123.960	€ 678.504	€ 123.960
	Discount rate	1,12		
	IRR	12%	IRR	14%
	NPV	-€ 58.801	NPV	€ 430.099

Appendix I: Steel part processing

Steel part processing process model

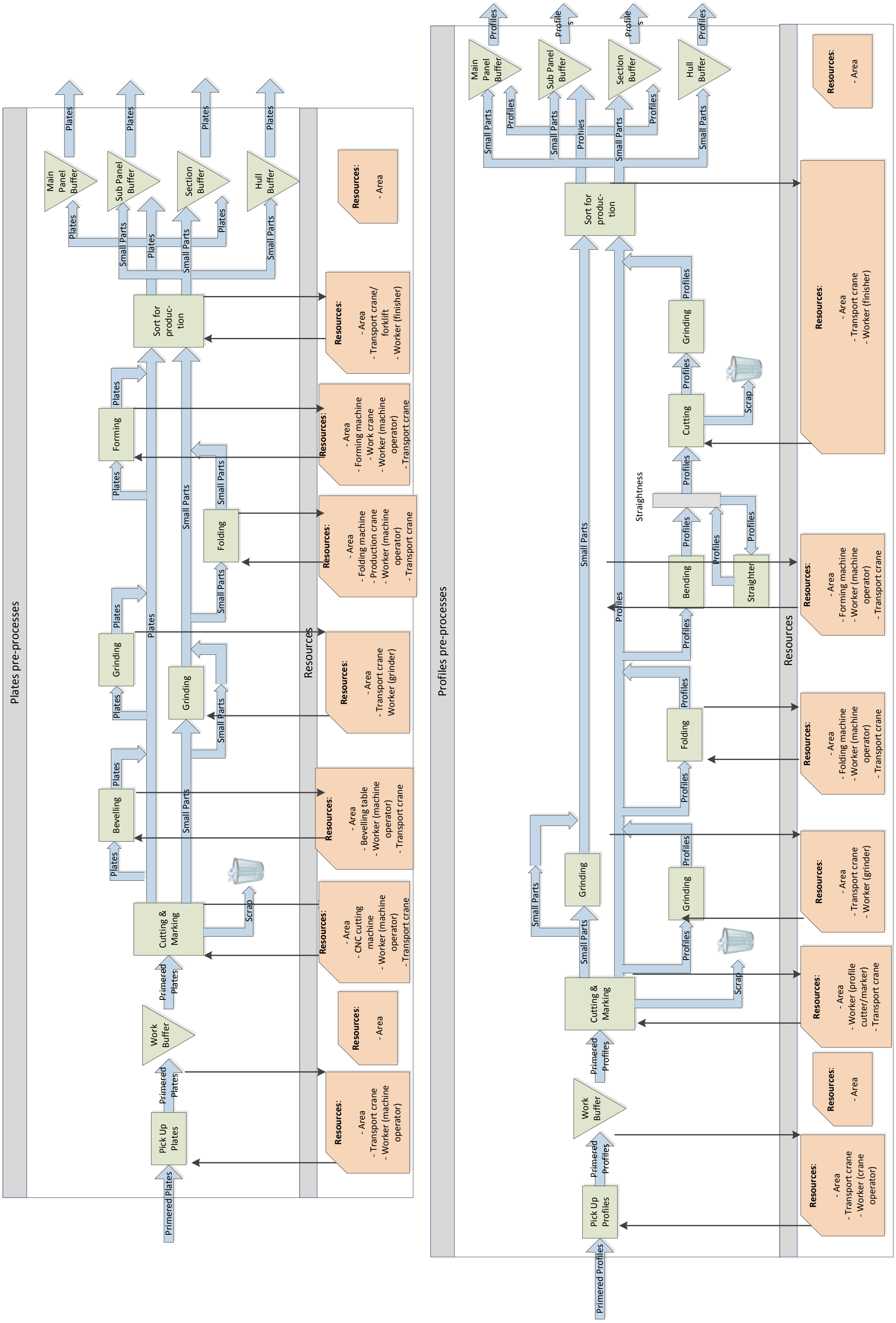


Table of hours/part, hours/m2, hours/m

Plates

[SLa5612; STu2208; SPa4207]	Cut and mark	Form	Fold	Bevel	Grind	Sort
Output/year required	[659; 411; 620] eq. tons	[0; 0; 0]	[624; 1000; 300] parts	[404; 435; 400] meters	[9480; 6000; 8000] parts	[1720; 1600; 1600] parts
Output/year capacity	3000 tons	(600 tons)	10000 parts	4000 meters	13200 parts	6600 parts
Workers	3	2	1	1	1	1
Transport move/part	1	1	1	1	1	1

Profiles

[SLa5612; STu2208; SPa4207]	Cut and mark	Form	Fold	Grind	Sort
Output/year required	[197; 76; 72] eq. tons	[21; 35; 17] eq. tons	[0, 0, 0]	[4724; 5000; 4200] parts	[1500; 1000; 1500] parts
Output/year capacity	880 tons	100 tons	10000 parts	13200 parts	6600 parts
Workers	2	2	1	1	1
Transport move/part	1	1	1	1	1

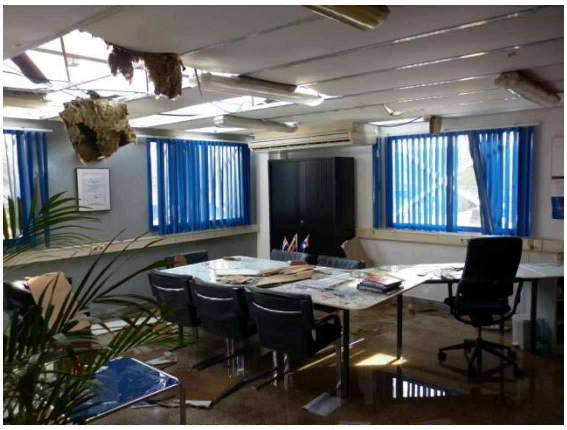
Investment analysis

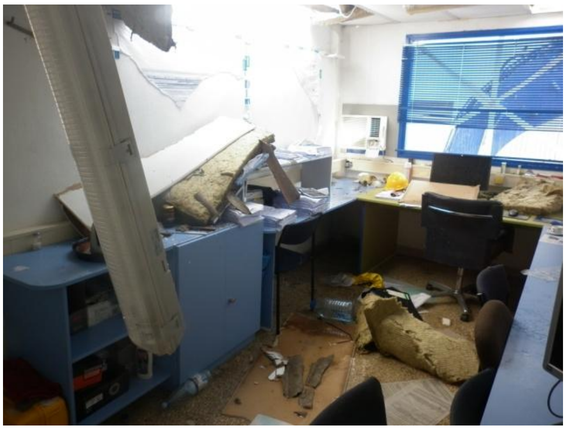
Year	As-is +0%		Cheap concept +46,6%		Max h. sec. o.f. conc +63,6%		Max sec. of. conc. +71,6%	
0	-€ 1.234.000	-€ 1.234.000	-€ 1.234.000	-€ 1.234.000	-€ 1.284.000	-€ 1.234.000	-€ 1.234.000	-€ 1.234.000
1	€ 150.000	€ 133.929	€ 219.900	€ 196.339	€ 245.400	€ 219.107	€ 257.400	€ 229.821
2	€ 150.000	€ 119.579	€ 219.900	€ 175.303	€ 245.400	€ 195.631	€ 257.400	€ 205.198
3	€ 150.000	€ 106.767	€ 219.900	€ 156.520	€ 245.400	€ 174.671	€ 257.400	€ 183.212
4	€ 150.000	€ 95.328	€ 219.900	€ 139.750	€ 245.400	€ 155.956	€ 257.400	€ 163.582
5	€ 150.000	€ 85.114	€ 219.900	€ 124.777	€ 245.400	€ 139.247	€ 257.400	€ 146.056
6	€ 150.000	€ 75.995	€ 219.900	€ 111.408	€ 245.400	€ 124.327	€ 257.400	€ 130.407
7	€ 150.000	€ 67.852	€ 219.900	€ 99.472	€ 245.400	€ 111.006	€ 257.400	€ 116.435
8	€ 150.000	€ 60.582	€ 219.900	€ 88.814	€ 245.400	€ 99.113	€ 257.400	€ 103.960
9	€ 150.000	€ 54.092	€ 219.900	€ 79.298	€ 245.400	€ 88.494	€ 257.400	€ 92.821
10	€ 150.000	€ 48.296	€ 219.900	€ 70.802	€ 245.400	€ 79.012	€ 257.400	€ 82.876
	Discount rate		1,12					
	IRR	4%	IRR	12%	IRR	14%	IRR	16%
	NPV	-€ 386.467	NPV	€ 8.484	NPV	€ 152.565	NPV	€ 220.367

Appendix J: Hurricane Sandy

My second visit was cancelled by the effects of hurricane Sandy. Some pictures are shown below. Pictures are from the DSGo database.






The power plant was damaged and shut down. Roads were blocked by trees. Most of the roofs of the buildings were blown off; office and production equipment was damaged by wind, debris and rain. Materials were blown from their storage; sections were blown away and damaged.