HEEREMA FABRICATION GROUP

Optimal acquisition and allocation of production equipment.

Providing more for less

Graduation Thesis

MSc. Construction Management and Engineering

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Bram Overgaag
4135571
Bramovergaag@gmail.com

TU Delft Delft University of Technology

Executive Summary

As projects tend to become larger and more complex, smaller elements become more interesting to analyze. For example, costs to provide production equipment correlate with a projects' size, which enables the execution of a research to optimize equipment budgets. The optimization of the use of equipment is not integrated to the same extend as labor optimization in the management of constructions. Heerema Fabrication Group is aware of this lack of control on equipment and formulated the framework and questions that will be answered in this research. With a yearly budget of over 9 million Euros, for providing equipment, they think doing research is justifiable. Trying to find even small improvement on such a budget may result in considerable savings and complies with the company's goal of continual improvements.

As the client for this research Heerema Fabrication Group (HFG) is specialized in the engineering and fabrication of large and complex structures for the offshore oil & gas and energy-related industries. Operating on several locations the goal of the research is to improve the Productions Equipment Management Structure (PEMS) at HFGs' Zwijndrecht location in the Netherlands. At this yard equipment maintenance is executed by the Asset & Facility Department (AFD). This department is responsible for providing the needed equipment at a specific time at a given location. Currently the AFD is not capable of making good forecasts, on needed equipment, necessary to make accurate budget estimations. The department can therefore not provide a clear financial indication of the Return on Investment (ROI) of their expenses. This research makes recommendations about how to organize equipment management and gain insight is the future use of equipment. A component of the new PEMS is a mathematical Integer Linear Programming (ILP) model, which links planned activities and available equipment (Inputs) and determines how to optimally acquire the required equipment (Output). In order to make a workable selection of equipment, the following requirements were established to narrow the scope:

- Equipment monitored in the current PEMS
- Equipment used for more than 2 activities

Having formulated a calculation model that can be integrated in the PEMS will provide new equipment management possibilities as the equipment is better monitored and parameters can be identified where improvements can be made. The discovery of these opportunities and their implementations formulate another objective of the research. In order to obtain a new PEMS that can be applied and used in the production process, it is important to generate and asses feedback and investigate how to involve stakeholders to make adaptations that increase the quality and applicability of the PEMS.

A framework defines the types of data required as input to the calculations of equipment management costs. In first instance a model is defined that determines optimal acquisition methods of equipment. Within the framework new calculation techniques are introduced and adjustments are made to the equipment demand used in the model. Once, the models are defined the results of the modification on cost calculation techniques can be observed and it can be determined which calculation adjustments are worth implementing in the production process.

Having described the calculation models, the results can be obtained and used to evaluate the newly introduced calculation techniques or modified framework. The results formulate an indication of the total costs of the PEMS, as a consequence of a certain modification, and enable the evaluation of that modification. Knowing if the costs are reduced can only be done if first the costs of the current management strategy are determined. Once this is done there is a reference point from which an analysis can be made about the quality and quantity of the improvements. From this starting point the results of step-by-step adjustments can be evaluated on the impact that each modification has on the equipment management expenses. The determination of most influential parameters will form the basis of the changes that are to be made as improvement of the equipment management strategies.

Having determined the important adjustments in order to reduce the expenses of the PEMS, the research is further concerned with how to implement these modifications. To be able to properly implement the changes, stakeholders are analysed. This is done to define the best implementation strategy and identify supporters and opponents of new management strategies. Besides the stakeholders other aspects (types of equipment, activities and management methods) of the environment are analysed to provide a full understanding of the PEMS environment. Once the setting of the PEMS is defined changes can be proposed to the management structure. The policy changes are described and evaluated on their costs and benefits to provide a full understanding of what efforts need to be made to realize a change in PEMS and reduce the required costs. The following measures/policies are proposed to be implemented;

- Using ILP.
- Reducing allocation.
- Creating internal cash flows.
- Focussing on workforce.
- Creating an *internet of things*.
- Using lean manufacturing.
- Continual renewal of equipment and requirement standards
- Providing more responsibility to the workers.

Using ILP and reducing the allocation factor are the best substantiated strategies, as they are measures within which costs and benefits have been determined numerically. The total benefits made by introducing these two measurements, once the maximal costs are deduced from the benefits, sum up to between 225,000 and 400,000 Euros. Additionally to the financial benefits enough equipment is then available for all workers. Implementing these measures makes it possible to provide more equipment at less cost.

Under the new PEMS, the AFD is provided a frequent update of the workforce planning by the production departments. Using the established equipment norms they can translate the workforce planning into a planning of required equipment. Based on this information the equipment can be provided at lower cost if ILP and an allocation factor of 0.67 where used. The reduction of the PEMS' costs can only be realized if other management strategies are modified in collaboration with the stakeholders.

As the new PEMS might be implemented following all or some of the proposed strategies its effectiveness becomes measurable. With data on the performance of the PEMS the inputs and framework can be (re)evaluated. The performance of the management structure could point out shortcomings of the estimations made. The sensitivity of some inputs needed to use ILP modelling increases the complexity and the accuracy of its implementation. Once, using ILP these sensitive parameters need to be identified and the users of the PEMS should be made aware of the impact on the reliability of those parameters. By implementing a cyclic process, norms will be updated continually allowing the model to become more reliable over time. The continual improvement of the reliability of the PEMS should lead over time to a theoretical model that describes the reality with more and more precision.

To enable the realization of the PEMS all adjustments might not be implemented at once. The order of implementation seems important as the performance will be evaluated before all changes are implemented. Implementing the simpler and most effective changes first might convince the stakeholders during the implementation process to understand the usefulness of making changes to the PEMS. The modifications of the PEMS can in this way gain support during the implementation process and have bigger chances of success. Additionally, some changes cannot be implemented before some policies are modified first. The figure below illustrates the proposed process of implementation in order to optimize the acquisition and allocation of production equipment.

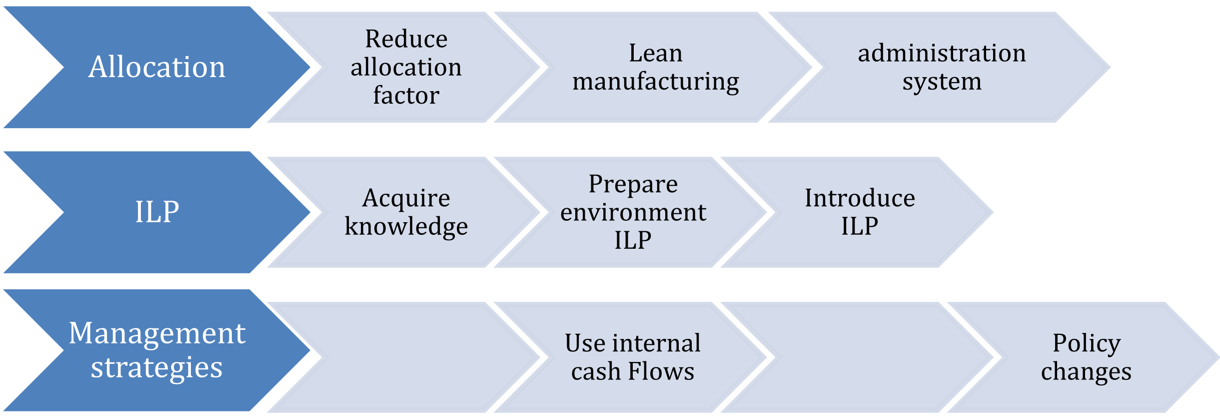

Figure 1 Implementation process

FABRICATION

Content

Part I Introduction

Conducting a graduation thesis research marks the final step in the educational process for a Master's course. The topic of this research complies with the educational program at TU Delft and the Master of Construction Management and Engineering. Learning more about the context in which projects are executed, combined with in-depth knowledge of theoretical project aspects, form the main cornerstones of knowledge acquired during this master program.

Looking for a research topic, the orientation was mainly on topics related to project management, as this seems something particularly interesting and relevant. Project management is defined (Kerzner, 2013) as a systems approach to planning, scheduling and controlling of resources. This approach must contribute to the construction of an object that meets certain specifications. As part of project management we consider the management of resources, in the literature focus is often put on the management of time, costs, and quality in order to reduce labor costs and speed up the construction process.

As projects tend to become bigger and more complex, smaller elements become more interesting to analyze. For example, costs related to production equipment grow with a projects size, which enables the execution of a research that optimize equipment budgets. Currently it seems that labor costs are the subject of many studies and management techniques. However, the optimal use of equipment is not yet integrated to the same extend in the management of the construction environment. Heerema Fabrication Group is aware of this lack of control on equipment and therefore formulated the framework and questions that will be answered in this research. With a yearly budget of over 9 million Euros for providing equipment, to them, doing research is justified. Trying to find small improvement on such a budget might result in considerable savings and complies with the company's goal of continual improvements.

Realizing such improvement needs to be done in a structured manner. In this part a description is made of the context, framework, and objective of the research. The elements form the basis of the research questions that are aimed to be answered by this research. The research model illustrates the strategy chosen to be able to answer the research questions.

1.1 Research context

As described on their website (Heerema, 2013) Heerema Fabrication Group (HFG) specializes in; *The engineering and fabrication of large and complex structures for the offshore oil & gas and energy-related industries.*

Founded in 1948 in Venezuela, Heerema started by constructing platforms, quays, piers, and bridges around the Maracaibo Lake. Around 1960 the activities were extended to construction in and around the North Sea. When in the eighties the oil prices collapsed, the company decided to acquire production facilities in Vlissingen and Zwijndrecht. Doing so Heerema enlarged its activities and secured its competitive position on the market. At that time Heerema group was created with two different divisions each specialized in the two main activities of Heerema; fabrication and contracting. Within time two extra divisions were added: Dockwise and Heerema engineering. These two divisions are now sold again and incorporated into the Heerema Marine Contractors and Heerema Fabrication Group divisions of the company. Heerema can be now be defined as the figure below shows.

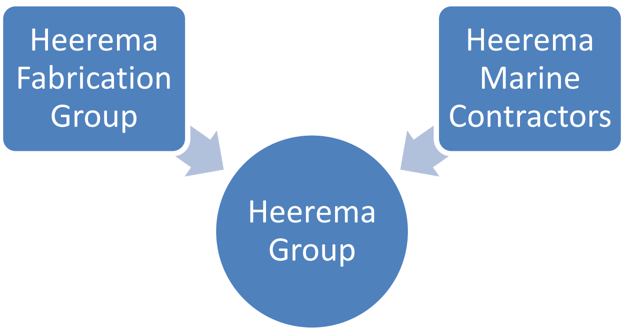

Figure 2 Heerema

The Heerema group has three offices in The Hague, Geneva, and Luxembourg that enable the execution of the groups' centralized activities. Heerema marine contractor has several offices around the world with their main location in Leiden, the Netherlands. The research, however, is executed for Heerema Fabrication group. This division has construction yards in Opole (Poland), Hartlepool (United Kingdom), Zwijndrecht, and Vlissingen (Netherlands). As the client, the research will focus on the fabrication division of Heerema and especially on the activities that are done at the Zwijndrecht yard.

The Fabrication Yard in Zwijndrecht is specialized in the delivery of complete oil, gas, and wind platforms. A great number of the activities to make a platform are outsourced to subcontractors and the company performs only those activities in which it is specialized. This strategy enables the company to focus on core activities and maintain a high degree of flexibility in an unstable economic environment. Constructing and assembling the steel structure of the platforms is one such specialized activity. Subcontractors that are simultaneously working on the yard on the other hand execute the installations and painting of the objects.

Each involved stakeholder of the fabrication process has the responsibility to bring and manage his equipment. For the core activities of fitting and welding this means that the company has to manage its own equipment. While collaborating with the production department, project managers, and yard management the Asset & Facility Department (AFD) needs to organize and manage the disc cutters, pin tolls, welding equipment, toolboxes, and other types of equipment.

In most modern firms, equipment maintenance departments (AFD) are increasingly important as production efficiency is managed more closely. More software tools and procedures are formulated to get equipment organized. In an environment and time where all costs need to be justified, these software tools provide administrative support for maintenance managers. Having a clear insight into the available and needed equipment, they can make a substantiated claim for more budgets in order to fulfill their responsibilities. At HFGs Zwijndrecht yard, equipment maintenance is executed by the AFD. This department is responsible for providing the needed equipment at a specific time at a given location. At the moment AFD is not in a position to make good forecasts of the needed equipment, which is necessary to make accurate budget estimations. The department can therefore not have a clear financial indication of the Return on Investment (ROI) of their expenses. This research aims to make recommendations about how to organize equipment management and make calculations of what the consequences are of making these adjustments. What such a model may look like and how this can lead to improvements to the current Production Equipment Management Structure (PEMS) is the basis for the research questions.

1.2 Research framework

Within most complex and large projects that HFG performs, close management of the projects and their processes has proven to be most efficient. When it comes to resource management, this is at the moment focusing on management of personnel and materials. However, another aspect of resource management has so far not been closely monitored within the production process at HFG.

Until now the equipment is provided in such a way that it is always available when employees need it. According to the number of activities executed at a given moment by the production departments an idea is formulated on how much equipment is needed. Equipment management is related to the planned quantity of workers, but the equipment managers do not use the planning of the workforce at this point. The approach of awaiting the equipment demand one month ahead from production managers has always been a safe and simple way to manage equipment and has not been contested. The incentive of this research is to enable equipment managers to have an indication of the theoretically financial most optimal acquisition methods of equipment, directly based on the workforce planning. A new way of establishing equipment demand can be used as a basis for the determination of how to acquire optimally the equipment needed to execute the project.

Two clients are involved in this research: TU Delft and HFG. This might create disagreements since they might have different interests. To avoid conflicts it seems important to clearly formulate the requirements and the limits of the research.

- The intention is to develop a new PEMS that will optimize acquisition of different types of equipment. However, the variance of equipment types is large and the scope is narrowed down to specific equipment types;
    - Equipment monitored in the current PEMS
    - Equipment used for more than 2 activities
- Assembling and organizing information will be a major part of the research and the construction of an appropriate ILP-model will consist of only 30-35% of the research. Defining the framework and possible variables used in the model are relevant for the quality of the model. The analysis of the environment in which the equipment is used seems relevant in order to find applicable improvements to the way in which equipment is currently managed.
- The aim is to obtain a new strategy to reduce costs of managing production equipment and integrate an ILP-model to determine the optimal method of acquiring the equipment. The adjustments to the PEMS should be adoptable for different firms and with different types of equipment.

Within the set boundaries of the research framework some specific knowledge is applied in the research. The determination of what knowledge to incorporate in the description of the proposed solution is a result of the literature study that can be linked to different aspects of production equipment. Based on this preliminary research some decisions are made about what methodologies are followed to reach the objectives of the research. This preliminary research investigates the knowledge available on optimization techniques, stakeholder analysis, and different aspect of organizational management.

In management science (Dantzig, 1998), mathematical optimization is the selection of a best elements from a set of available alternatives. A few sub-fields of knowledge of these mathematical optimization sciences are; convex programming (Bertsimas and Tsitsiklis, 1998), integer programming (Steiglitz and Papadimitriou, 1982), and quadric programming (Wolfe, 1959). Each field of knowledge corresponds to the optimization of a problem described in specific variables. As described in the research ILP is the used optimization technique in the new production equipment management structure. The model links planned activities and available equipment (Inputs) and determines how to optimally acquire the required equipment (Output). Aternatively to mathematical optimization, the best acquisition methods can only be determined based on estimation and no research is available that prescribes methodologies to acquire production equipment.

To be able to realize the adjustments of the new PEMS a description is made of different implementing techniques and a stakeholder analysis is executed to make the adjustments realistic. The stakeholder analysis aims to asses which and how to involve parties during the implementation process. Once identified, the stakeholders can be mapped based on the dimensions of power, support, influence, and need. Possible mapping techniques are: Influence/interest grid (Manowong and Ogunlana, 2009), Power/impact grid (Kelly and Alam, 2008), power/interest grid (Mendelow, 1981), a three dimension grouping of power, interest, and influence (Murray-Webster and Simon, 2006), and making a stakeholder circle (Bourne and Weaver, 2009). For the purpose of the implementation of changes to the PEMS the mapping according to the power interest/grid seems obvious, as direct approaches are know (De Bruijn et al., 2008) to deal with the stakeholders once they are mapped following this mapping technique.

The actual realization of the changes that are necessary to make are prescribed on basis of knowledge acquired during; studies on operation management (Slack et al., 2010),(Nahmias and Cheng, 1997), the analysis of lean manufacturing, especially the 5S methodology (Antony et al., 2003), a study of possible supply chain management strategies (Christopher, 2010), an investigation on storage possibilities (Kudva et al., 1994), and an inquiry into organization management (Pfeffer, 1998). Within this literature examples and ideas are found that are translated in concrete strategies. These strategies should make it possible to realize the calculated cost reductions to the PEMS and need to be applicable in an environment where the studied equipment is used.

1.3 Research objective

The aim of this graduation research is to reduce the expenses made to providing equipment at HFG yards. A model will provide guidance to optimally define the acquisition methods and allocation of equipment. This equipment is used in a fabrication environment where large prefabricated structures are assembled.

This objective is captured by the following questions:

- How to optimally acquire the equipment by, for example, buying or renting the tools?
- How to distribute the available equipment efficiently over the work floor?

To reach the objective stated in the beginning of this section, the recommendations will need to satisfy/answer the research requirements and questions. The optimization problem is defined by a model of which the results give a better idea of how to acquire required equipment. Using ILP and basing it on future planned activities should make it possible to see how the equipment requirements fluctuate over time and the AFD will be provided with a better argumentation for acquisition decisions.

Having formulated a calculation model that can be integrated in the PEMS will provide new equipment management possibilities as the equipment is better monitored and parameters can be identified where improvements can be made. The discovery of these opportunities and their implementations are also components of the research. In order to obtain a new PEMS that can be applied and use it in the production process, it is important to generate feedback and make adaptations to increase the quality and applicability of the PEMS. To obtain the necessary feedback, the research will be executed under the supervision and instruction of HFGs yard in Zwijndrecht.

As a result of the research the company will be provided with information that grants them more control over their equipment. The aim is that the control on equipment goes as far as the control they have over labor management. The research should determine an optimal distribution of acquisition methods for production equipment and investigate the allocation of equipment over the production workers. This should enable the company to provide more equipment to the production workers at lower cost. The procedure intends to use optimization techniques that can be generalized for a large number of activities on the Zwijndrecht production yard. Ultimately, the model should be usable on the different yards and applicable at other firms as well.

1.4 Research questions

To be able to check whether the research has been executed to the clients' satisfaction research questions are formulated (Verschuren and Doorewaard, 2007). The main research question is;

What improvements can a Production Equipment Management Structure (PEMS), integrated with optimization techniques, bring to the determination of an optimal method of acquisition of equipment, required in an industrial environment, in order to reduce costs?

This main question is a result of the following sub-questions that are asked.

- What is the current management structure used to determine the quantity of equipment?
- What is the available equipment?
- How is the equipment used during the activities?
- What acquiring methods are currently used?
- What are the acquisition costs of the equipment?
- What are the different types of activities executed at the Yard for which the studied equipment is used?

Having acknowledged the current manner of managing equipment, adjustments can be proposed and this leads to a new set of questions

- What acquisition methods would an ILP-model prescribe if it were integrated in the PEMS?
- How can an ILP-model link the activities with the available equipment?
- What does a new PEMS look like if it integrates an ILP-model?
- What costs does the new PEMS predict with the current activities?
- What are the characteristics of the new PEMS?
- What are the predictions for future equipment requirement using the new PEMS?
- What changes are necessary to implement the new PEMS?

1.5 Research model

In order to answer the questions in the previous paragraph, a set of activities are assembled in the following model.

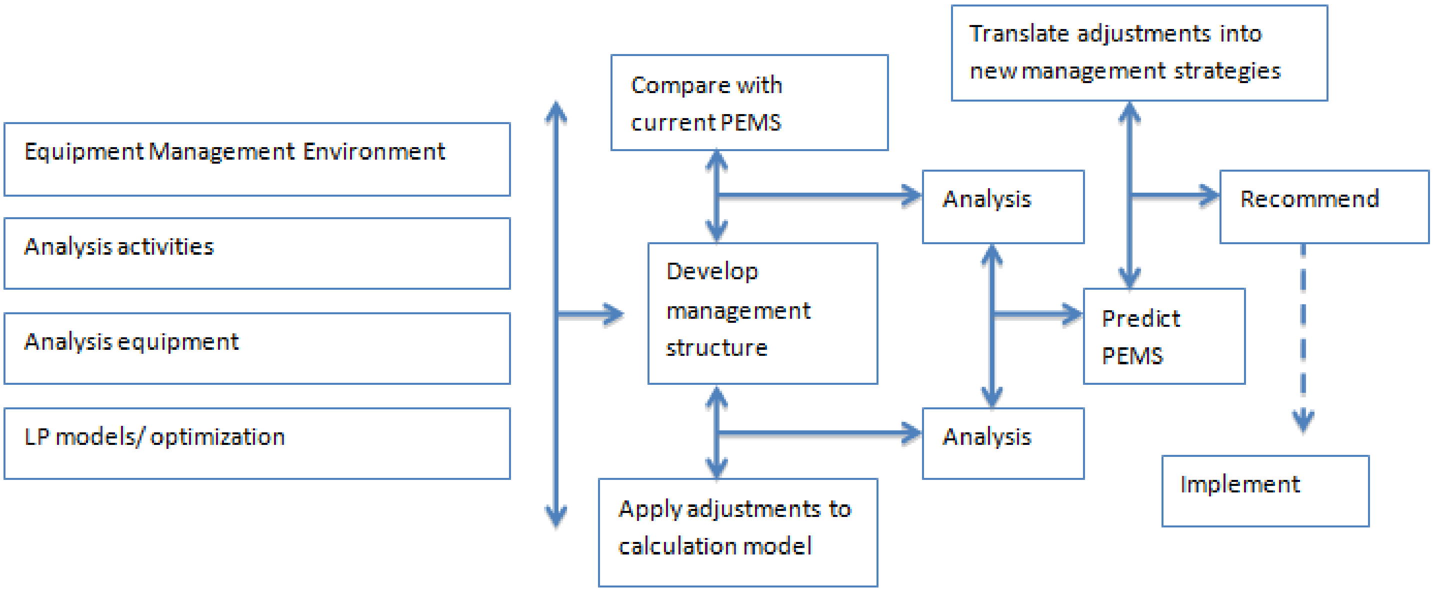

Figure 3 Research model

An elaborate study of the equipment management currently in place will provide a reference point for the research and will be used to measure the effects of the solutions. Further analyzing and inventorying the equipment and activities can help formulate a description of the practical reality at HFG yard Zwijndrecht. The observations made about the surrounding of the Production Equipment Management Structure (PEMS) are captured in the inputs and framework of the calculation techniques.

Having established a framework, a mathematical model can be created to determine most optimal acquisition methods. The obtained model can be tested using information about projects completed in the past and projects executed at the moment. Comparison with the current PEMS will enable the determination if the adjustments are improvements. Performing the calculations, sensible parameters can be identified and the significance of those parameters on the cost of equipment can be monitored.

Once the model has predicted the optimal quantity of equipment of the studied projects it can be integrated in a new PEMS. Realistically, some modifications need to be made and possibly new adjustments can be added that will extend the possibilities of the PEMS. To enable the realization of the calculated improvements, some changes in management strategies must be made to implement the new PEMS. With the new model, predictions about the quantity of equipment required for future projects can be made and recommendations concerning management strategies can be shaped.

1.6 Reader guidelines

To realize the objectives of this research the report is built up in different parts:

Part II describes the model that has given rise to the improvements to the PEMS. To formulate this model, a framework is established that establishes the boundary of the usable calculation techniques. The description of the framework defines the difference between parameters that can be changed that will only influence the results (inputs) and the elements that if changed would imply setting up a whole new model (framework). The number of parameters is modified during the description as new acquisition methods and a modified allocation factor are applied as improvement. Integer linear programming is introduced and the effects can be measured by letting a solver determine the optimal manner of acquiring equipment. The consequences of making the proposed changes are measureable once the results are calculated. This is the subject of the next part.

In Part III consequences of using different calculation procedures are measured by observing the impact they have on the costs of equipment management. The consequences of each of these adjustments are in order to evaluate what improvements are realistic enough to be used and applied in a production environment. In the first series of results, the costs are calculated of how the equipment is currently managed. This constitutes a reference point. Observing the introduction of each calculation procedure separately enables an evaluation of each adjustment and the impact they have on the predicted management costs. In the last step of this part the adjustments are translated into implications for necessary changes. These changes should be used when proposing improvements to management policies in part IV.

In part IV the necessary changes are described in order to be able to use ILP and the reduction of the allocation factor. Further to this the benefits of using ILP as an estimation of the costs accompanied with introducing this new management strategy, are described in this part. Other new strategies that are proposed to be implemented are the creation of internal cash flows and a change of equipment allocation. To support these new management strategies, additional policy changes are described. These changes seem necessary to make in order to ensure implementation on the long term of the improvements to the PEMS. These management ideas are: the focus on workforce, *Internet of things* (Slack et al., 2010), and lean manufacturing. This part is concluded with some indications about what parameters are relevant for guaranteeing a sustainable amelioration of the PEMS.

Part V marks the final step of the research and summarizes the recommendations and findings of the research. The findings of the research are tested against the research questions to evaluate whether the objectives of the research have been reached. The new method of implementing equipment management, the result and the necessity of implementing the methods are described in this last part.

Part II Modelling

To be able to make a structured proposal for improvement, adjustments need to be made measurable to evaluate the modifications. A measurable and important parameter of management strategies are the expenses needed for a chosen approach. To realize the research objective, the modifications will therefore be measured on the impact they have on the costs. First, a calculation model is defined that determines the costs of managing equipment. A framework is set up to define the type of data required as input to the calculations of equipment management costs. Within this framework, new calculation techniques are introduced and adjustments are made to the calculation of management strategies. In the next part, the results of these modifications on cost calculation techniques can be observed and it can be determined which calculation techniques are worth implementing.

As Figure 4 summarizes; once the framework is determined, ILP is introduced to determine the optimal acquisition method. To this optimization technique extra possibilities are added. Besides, looking at acquisition calculations, modifications are added to optimize the allocation of equipment.

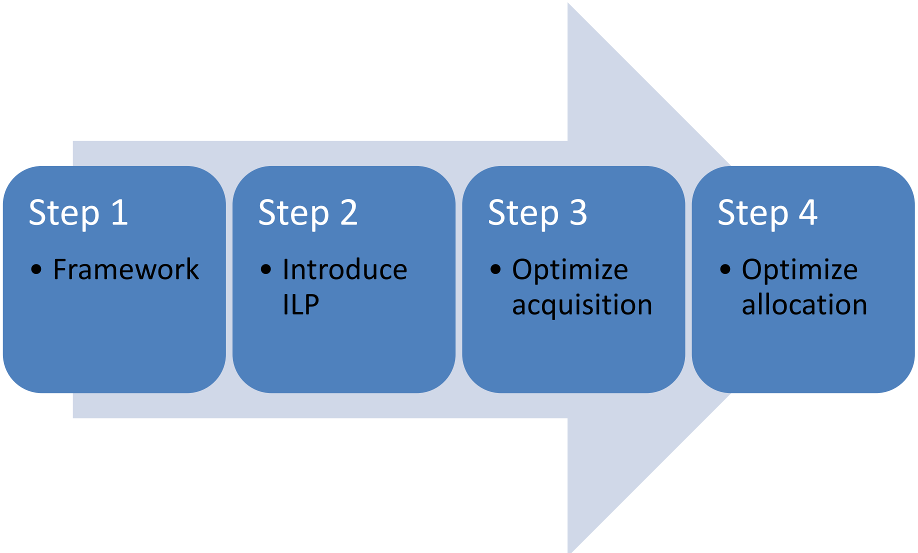

Figure 4 Calculation steps

2.1 Framework

Provided with data about the acquisition costs, workforce planning and start stock data is available to make cost calculations and make predictions of equipment requirements. In appendix III the initial data used is justified and several aspects of the inputs are tested to ensure the reliability and accuracy of the research. These inputs form the basis of theformulation of a framework for the calculation model.

The first step of the calculations involves the investigation of the current management structure. This step will be relevant to understand how the costs are defined and on which inputs they are based. The data that is used as a basis for making improvement to the PEMS is divided into two categories: framework and inputs. Establishing the framework will enable the start of calculations. The input (appendix III) that is used to formulate the framework is not directly relevant for performing the calculations. Making different inputs would still permit to perform the calculation following the same procedures. Formulating a different framework would require the review of all calculation steps.

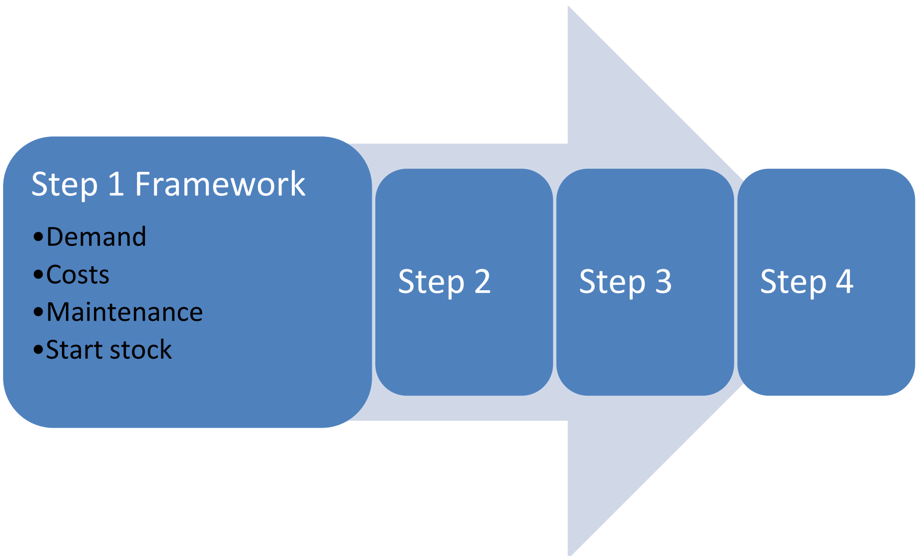

Figure 5 Step 1 Framework

2.1.1 Demand

The predictions of equipment demand is based on the planned workforce and equipment norms as explained in paragraph 2 of appendix III. The predictions provide the information of how much equipment should be arranged at a given moment. The planned workforce does not all work at the same time and at the change of their shift some equipment is transferred from one worker to another. Dependent on how much work there is to be done most of the people are working during the day shift. Using this shift as standard for equipment estimations, planning equipment for this shift enables to always provide enough equipment for all other shifts as well. Currently some equipment is allocated to each worker while some of the equipment is transferred between workers at the beginning/end of the shift.

To transform the equipment demand to the demand that is used in the calculation model it is multiplied with the allocation factor. When a piece of equipment is directly allocated to a worker the allocation factor is 100% or 1. If the equipment is, however, transferred between workers an allocation factor of for example 67% or 0.67 is maintained. An allocation factor of 0.67 corresponds to the shift needing the largest amount of equipment; the day shift. Two third of the production workers are working during this shift and the demand of equipment is the highest at that moment. In the other shifts, less equipment is used and once enough equipment is provided for the day shift there will automatically be enough equipment available for the other shifts. The types of equipment transferred between shifts are all the equipment types except for the disc cutters, pin tolls, cutting torches and toolboxes. The latter types of equipment are those that are allocated for 100% at the moment. The required quantity of equipment is determined based on the inputs explained in paragraph A.3.2 and this quantity formulates the framework of the cost calculations.

Variable		Description	Value
Equipment demand	=	Planned quantity of workers *Equipment norm * Allocation factor	$D_{i,j}$
Planned quantity of workers	=	Initial data	
Equipment norms	=	Initial data	
Current allocation factor			
Welding and distribution	=		67 %
Fitting and toolboxes	=		100 %

Table 1 Demand framework

2.1.2 Costs

The information provided about costs as described in paragraph 2 of appendix III consists of only three values that need to be transformed into series of information that describe equipment costs for each week of the planning period. This planning period goes from week 1 until week 52 and is updated frequently. The three provided variables that are the basis for the determination of costs are: Procurement, Operational and Rent. In the initial calculation model two acquisition methods are used: Rent and Procurement. The costs of these acquisition methods are established as follows:

Rent; as an acquisition method rent can be calculated quite easily. The costs made when choosing for the rent acquisition methods are equal to the rent variable provided in the initial data. If it is chosen to acquire equipment through rent it is considered that no further operational costs have to be taken into account. The term operational cost refers to maintenance costs since consumables and electricity/resources have to be paid for independent of the acquisition method. These expenses are equal for all acquisition methods and they are not taken into account in this analysis. Rent costs are relatively small but they have to be paid every week and the stock is only increased for one week. Renting is an acquisition method that will be mostly used to cover short increases in equipment demand.

Procurement; Opposed to renting, the procurement acquisition method concerns a bigger investment but it will increase the stock for the rest of the planning period. If equipment is procured that also means that maintenance costs need to be paid. The costs in the first week of the planning interval are determined by adding up the procurement costs and the maintenance costs for the whole year. If the equipment is procured the second week the price will be similar, however the left over maintenance cost decreases a little bit. This decrease equals the maintenance costs that would have been paid in the last week. Procurements cost decrease gradually until in the last week the cost of procurement equals only the purchase prize. In the next paragraph the evolution of maintenance costs is further described. Procurement is an acquisition method that will be mostly used for long periods of increases in equipment demand.

Variable		Description	Value
Rent costs per week	=	Rent	$C_{i,t,1}$
Procurement costs in week t	=	Procurement + Yearly maintenance Costs – Maintenance costs of last t weeks	$C_{i,t,2}$
Rent	=	Initial data	
Procurement	=	Initial data	
t	=	Weeks since procurement	

Table 2 Cost framework

2.1.3 Maintenance

Maintenance costs are not the same in each week but they increase over time following a cumulative exponential distribution due to ageing of the equipment. This distribution is used to determine the probability failure rate of equipment (McCall, 1965)

$$F(T) = 1 - e^{-\lambda t}$$

In this equation the variable t corresponds to the number of weeks since the equipment is procured. The variable λ is the expected number of failures per week. In this case we assume that equipment is failing 4 times per year(Pluijmers, 2013) which corresponds to λ =0,08. The figure below illustrates the evolution of failure factor over time.

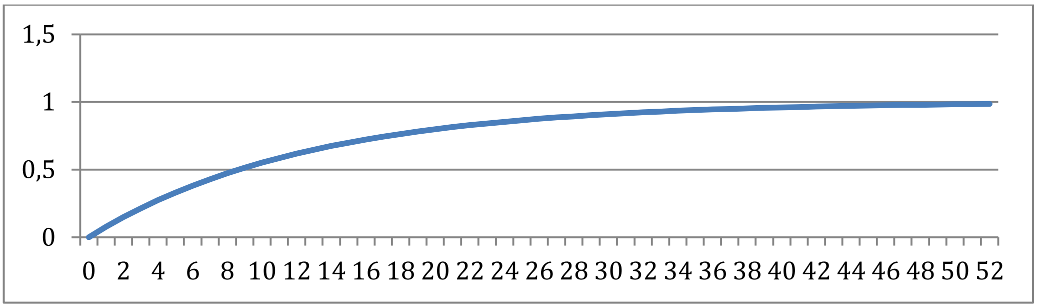

Figure 6 Failure factor

The failure factor is multiplied with the average maintenance costs and the result of this computation will give the operational costs in a given week t. The yearly maintenance costs are obtained by adding up 52 consecutive weeks of maintenance costs. The table below shows how the framework of the maintenance costs is formulated. Based on this framework the procurement cost are determined in the previous paragraph.

Variable		Description		Value
Yearly maintenance costs	=	52 weekly maintenance costs		
Weekly maintenance costs	=	Operational costs* Failure rate		
Failure factor	=	Exponential Distribution	F(t) = 1-exp(-λ*t)	
λ	=	4 failure per 52 weeks		0.08
t	=	Weeks since procurement		
Operational costs	=	Initial data		

Table 3 Maintenance framework

2.1.4 Start Stock

The determined equipment, demand can be provided in two different ways: acquisition or by using the stock that is already available. The quantity of equipment needed for acquisition is the information that is to be determined with the help of the model. The quantity of equipment acquired is directly dependent on the start stock. To determine extra quantity that the model needs to acquire the start stock is reduced from the quantity of equipment required from the workers. The model calculates the additional quantity of equipment needed to suffice the equipment requirements. The quantity of equipment available in the start stock determines the extra quantity required and needs to be established precisely. As the research concerns only equipment that is monitored, the precise quantity of equipment can be determined by using the monitoring database.

The quantity in the monitoring system does deviate slightly from the real quantity of equipment available for the workforce. This variation in quantity can have several causes going from theft of equipment to losing a piece of equipment off-site. The reason for the variation is not relevant to identify at this stage of the research, it should, however, be analysed how big this difference is.

For some types of equipment a secondary administration system is available and can be used as a back-up source of information. The availability of these secondary administration systems depends on the person responsible for the repairs of that specific equipment type. If this secondary administration system is not available, the quantity of equipment can only be verified with a manual count of the equipment on the work floor. The checking of the start stock using these secondary administration systems increases the reliability of the data used for the calculation of the management model. The analysis of the exact start stock contributes to the overall reliability of the outcomes of the model and further research of the precise amount of equipment at the yard would further augment the quality of the model. The exact quantity of equipment composing the start stock is provided in Table 4 in which the equipment allocated 100% to the workers can be identified with an asterisk.

# Equipment Type	Quantity		
1 Disc cutter*	386	10 Distribution unit light	30
2 Pin toll*	127	11 Distribution unit mixed gas	43
3 MIG welding machine	117	12 Distribution unit Natural gas	21
4 TIG welding machine	65	13 Distribution unit compressed air	23
5 Tack welding machine*	101	14 Mobile distribution unit	37
6 Gouging machine	30	15 Distribution units	132
7 Welding vapour extractor	29	16 Forklift truck	1
8 Cutting torch*	20	17 Welder Toolbox*	217
9 Beetle portable gas cutter	11	18 Fitter toolbox*	146

Table 4 Start stock

2.2 Introducing ILP

At this stage of the research, it has been acknowledged what the framework of costs calculations related to the current PEMS are. If modifications are made to the calculation model at this point, we can evaluate them based on the impact on the costs. Based on the effect on the costs this adjustment can be considered as improvement or deterioration. The changes with the biggest impact are identified in part III, where the results are determined and it can be concluded what changes would reasonably be implemented in the management system. Integer Linear Programming is introduced as the first modification made to the calculation model and the determination of acquisition methods. The use of ILP is necessary to evaluate other modification as it determines the optimal acquisition methods and from the model the total management cost can easily determined. A brief description is made of Integer Linear Programming and this knowledge is used in the application of the modelling done in this part of the research.

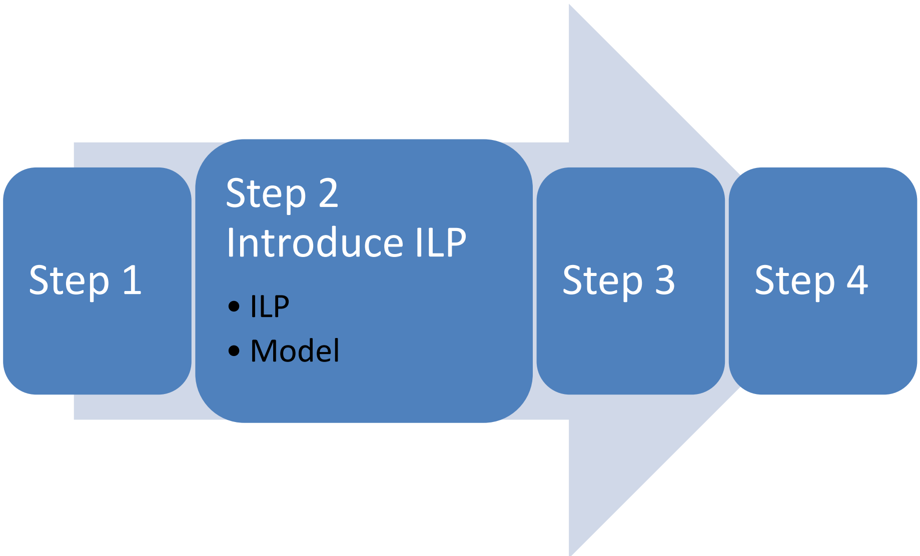

Figure 7 Step 2 introducing ILP

2.2.1 Integer Linear Programming

The decision to procure or rent a certain type of equipment to fulfill a certain demand of equipment in a given week has an impact on the costs the PEMS. Renting is generally more interesting for shorter periods and purchases become more interesting if equipment is needed for longer periods. For each demand, an optimum exists for choosing each of the acquisition methods. To determine such an optimum, calculation techniques exist, but to use them the problem needs to be defined as a linear problem. An LP can be executed in two directions minimization or maximization. The standard form of an linearization problem (Steiglitz and Papadimitriou, 1982) is as follows:

$$\begin{array}{ll} \text{maximize} & \mathbf{c}^{\mathrm{T}}\mathbf{x} \\ \text{subject to} & A\mathbf{x} \leq \mathbf{b} \\ \text{and} & \mathbf{x} \geq \mathbf{0} \end{array}$$

Where

x The n-dimensional vector composed by the variable sto optimize,
c The n- dimensional objective coefficient vector,
A The integer coefficient m*n matrix with indices corresponding to the constraints,
b The m-dimensional constraint vector.

In Figure 8, we can see a graphical representation of such an LP if it were to be defined by variables in a 2-dimensional space. The green, yellow, blue and red line together with the x and y-axis in the figure represent the constraints of the LP problem (Ax ≤ b and x ≥ 0). The constraints together limit the feasible solution area that is illustrated in orange in Figure 8. The most common optimization problem is the Linear Programming problem that accepts all the solutions on the orange colored area. The extreme solutions can be found on the outlines of the solution area and at the intersection of two constraints a basic feasible solution is defined.

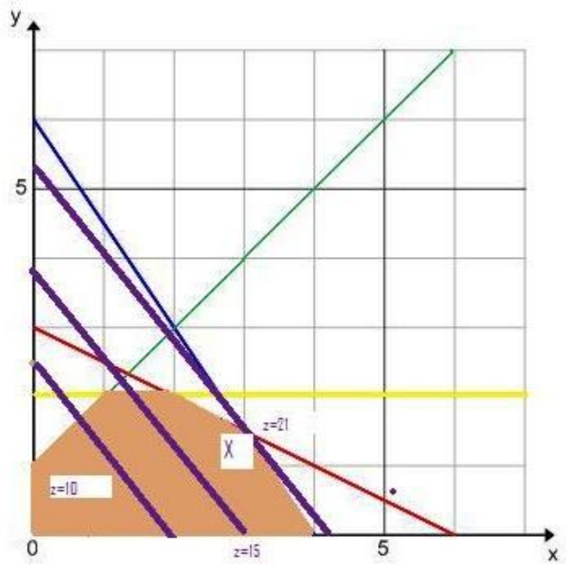

Figure 8 Graphic representation LP; source (Shahabels, 2008)

To find the best solution for an LP problem we need to screen the model for a global optimum. So far, we have not defined the objective function graphically. In the graphical example the purple lines represent the object function (C^Tx) for different values. To discover the global optimum in case positive coefficients are used the line is moved in a parallel manner toward bigger values of X and Y (maximization problem). In a situation of a minimization problem the function is displaced in a parallel manner towards lower values for X and Y. The point where the function crosses the last point of the solution area is the global optimum. For most of the optimization problems finding an optimum graphically is not possible and therefore, in for a lot of problems the Simplex algorithm of G.B. Dantzig is used to solve LP problems.

At this point the simplest category of optimization problems is defined. In reality a large number of problems are not defined as continuous variables but as integer variables. For these optimization problems another category is defined; Integer Linear Programming (ILP). An example of ILP is the optimization of the number of factories needed at specific locations to perform production optimally. The calculation of this ILP can only result in integer values of X such as 2 or 3. The possible solutions are needed to be natural numbers, as a tenth of a construction yard cannot be accepted as a solution. This constraint increases the complexity of the problem to solve as the figure below shows. The difference between Linear Programming and Integer Linear Programming is that the first one is defined in continuous variables while the second is only defined in integer variables.The feasible region of an ILP is not convex since not all solutions that can be found between two feasible solutions are also feasible. Having acknowledged what ILPs are, the acquisition problem can be defined as an ILP.

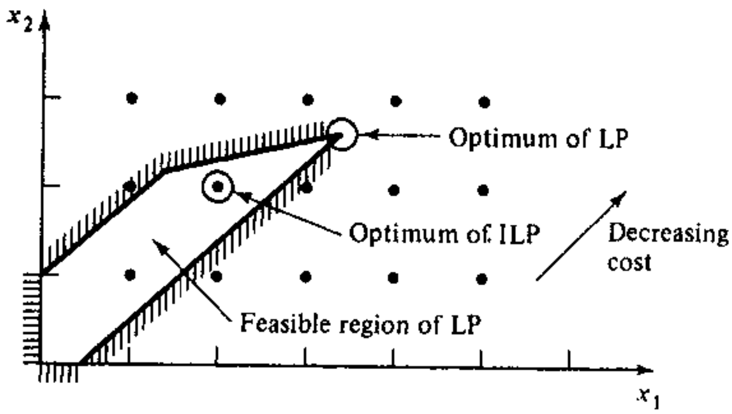

Figure 9 Differences LP/ILP (Steiglitz and Papadimitriou, 1982)

2.2.2 Model

In general ILPs are formulated in the form that an objective function is defined and associated with relevant constraints. In the objective function all the variables are assembled that need to be optimized. In the formulation of the ILP it is also specified in what direction the problem needs to be optimized. Constraints are specified to explain the behaviour of the variables in the objective function and to satisfy the requirements.

Specifically for each type of equipment, week, or acquisition method, which are the sets I, J, and K of integer values, the variables are defined. The set I = [1, 2, ..., |I|] with cardinality |I|= 18 is the set of equipment types that is studied. In paragraph 2.1.4 it can be found what value corresponds to what equipment type. The set J = [1, 2, ..., |J|] is the set of weeks composing the planning horizon. The planning forecasts for maximum one year ahead and therefore the cardinality is|J|= 52. The last set K = [1, ..., |K|] with cardinality |K|= 2 describes the different acquisition methods; k=1 corresponds to renting equipment and k=2 corresponds to purchasing equipment.

The first constraint is formulated with an input $D_{i,j}$ and variable $S_{i,j}$. $D_{i,j}$ is the input that represents the demand of equipment that is needed to perform the planned activities. The variable $D_{i,j}$ in which i represents the type of equipment and j the week in which this demand occurs; it is calculated following the procedure explained in paragraph 2.1.1. The variable $S_{i,j}$ represents the stock quantity that is obtained; it is specific for every week and equipment type. A special input value for $S_{i,j}$ exists which is $S_{i,0}$ or the quantity of stock that is owned by the AFD at the beginning of the planning horizon. In paragraph 2.1.4 the quantity available in the start stock is provided.

To optimize equipment acquisitions the following optimization problem can be described mathematically:

$$\text{Minimize } Z = \sum_{i \in I} \sum_{j \in J} \sum_{k \in K} C_{i,j,k} X_{i,j,k}$$

subject to

$$S_{i,j} \geq D_{i,j} \qquad \forall_{i \in I, j \in J} \qquad (1)$$

$$S_{i,j} = S_{i,j-1} + \textstyle\sum_{k \in K} X_{i,j,k} - X_{i,j-1,1} \qquad \forall_{i \in I, j \in J, k \in K} \qquad (2)$$

$$\text{For all } S_{i,j}, \ X_{i,j,k} \in \mathbb{N}_0 \qquad \forall_{i \in I, j \in J, k \in K} \qquad (3)$$

The used variables and sets are recapitulated in Table 5 and they are used in the mathematical model of the ILP given above. The variable Z describes the total costs that are made if ILP is used to determine the optimal acquisition methods. This solution is part of the feasible solution area defined by the constraints (1), (2) and (3). The value of Z is determined by the sum of the combinations from the values of the variables $X_{i,j,k}$ and $C_{i,j,k}$. $X_{i,j,k}$ is the variable that represents the quantity of equipment. $C_{i,j,k}$ is the input that describes the acquisition costs made for each unit of $X_{i,j,k}$ and in paragraph 2.1.2 it is described how they are calculated. The variable $X_{i,j,k}$ and the input $C_{i,j,k}$ are specific for each equipment type i, week j, and acquisition method k.

Parameter	Description	Used sets	Sets	Description	Possible Value
X	Quantity of equipment	I,J,K	**I**	Types of equipment	1,2,…,18
C	Acquisition Costs	I,J,K	**J**	Weeks	1, 2, …..,52
D	Demand of equipment	I,J	**K**	Acquisition methods	Rent 1
S	Stock	I,J			Purchase 2
$S_{i,0}$	Start Stock				

Table 5 Used parameters initial ILP

The stated mathematical expression describes the following optimization problem:

Minimizing the costs of all acquisition methods, all types of equipment, and for all weeks.

The optimization problem is subject to the following constraints:

(1) The stock for any type of equipment at any moment is larger or equal than the demand for any type of equipment at any moment.

(2) The stock for a certain type of equipment in a certain week is built up by the stock of that specific type of equipment in the previous week.

- **Added to that are all the acquired equipment in that week for all acquisition methods.**
- **Subtracted from that are all the rented equipment of the previous week.**

(3) All variables need to be Natural Numbers.

From the last constraint we can see that the equipment management problem is one of the categories of ILPs. This constraint places the optimization problem in a category of problems that are more complex to solve than linear programs. The ILP at this point is already built-up by 18*2*52= 1872 different values for the variable X. Only writing out such an ILP would require a very long time. Using software to solve the optimization problem makes it possible to realistically make calculations on the optimal acquisition methods for production equipment. A very accessible software package such as excel could be used to solve the simpler class of LP problems. Calculating the solutions of an ILP, however, requires more specific software.

Using a software package has the advantage that it does not require writing out the model with all its variables. The software can automatically read out the optimization problem once the ILP is defined using an Algebraic Modelling Language (AML). Advanced Interactive Multidimensional Modelling System or AIMMS(Bisschop and Entriken, 1993) is such an AML and a software package that can be used to solve the equipment management optimization problem. The AIMMS package uses a CPLEX (a software package developed by IBM(Cplex, 2010)) toolkit to solve integer linear programs.

The decision to pick the AIMMS software package to execute the solver is firstly based on the fact that a free educational licence can be provided. Secondly, AIMMS is a broadly used software package by other universities and companies. The use of a broadly applied software package increases the accessibility of its usage and data for a larger number of people.

2.3 Improvements

Having introduced ILP, an evaluation of this new PEMS can be made and further adjustments can be added to increase the possibilities of the management system. In the first model, only two acquisition methods are used, after performing some interviews with suppliers it seemed reasonable to add more acquisition methods as described in paragraph 2.3.1. Choosing for other acquisition methods can have an impact on the cost of the PEMS as it concerns a large quantity of equipment. Another dimension is also added to the acquisition strategies, which is the possibility of resale. Making an extension on the acquisition possibilities will require updating the ILP-model and changing the behaviour of certain variables. Apart from introducing new acquisition methods a different improvement is made to the calculation model in paragraph 2.3.2; the reduction of the allocation factor. This modification means a change in equipment demand and has an important impact on the PEMS performance.

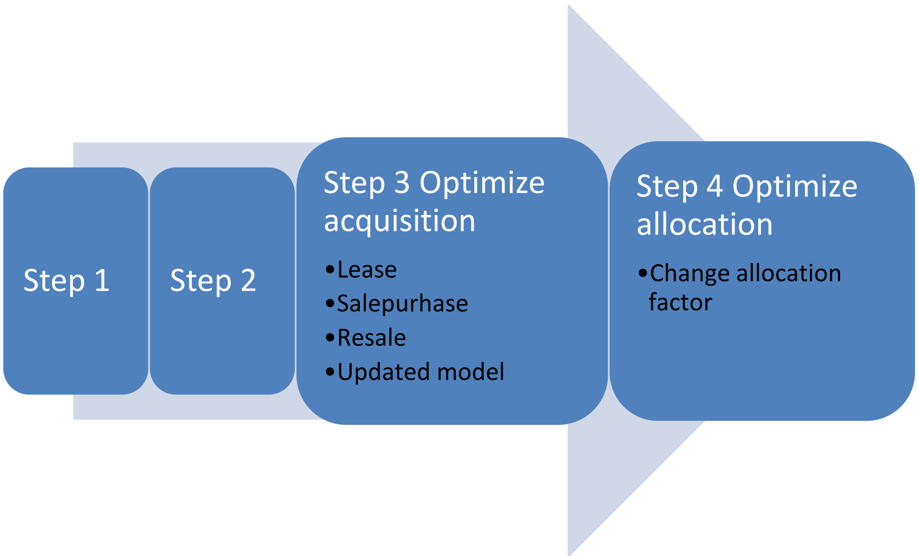

Figure 10 Step 3/4 Optimization

2.3.1 Acquisition methods

For different types of assets there exist a large variety of acquisition methods. The type of asset has an influence on what acquisition method is commonly used. A house for example might be procured, rented or it might be acquired through a mortgage plan. For a different asset such as a car leasing is more appropriate than getting a mortgage. This example illustrates the influence the type of asset has on the possible acquisition methods. In this research only the financial aspects are taken into consideration and some acquisition methods are not really distinguishable. A purchase or a mortgage plan for an asset that is paid off within one year has no distinguishable difference from an accounting perspective for example. Practical implications are not taken into account since the research evaluates equipment management only on financial performance.

2.3.1.1 Lease

Especially for the acquisition of cars, leasing is popular as maintenance costs are not a risk for the user anymore but the leasing company has to ensure that maintenance is done. Leasing can be compared with renting, as the services provided are quite similar. In this study we consider that leasing and renting are based on the same weekly renting price. In case production equipment is leased, the agreement with the leasing company is for a longer period of time than with renting. Due to this minimal period in which the supplier is sure to have rented out the equipment he is able to give a discount on the rental price. In the research it is assumed that by leasing equipment for a period of 20 weeks the obtained discount is 75% of the rental price. With these inputs we can formulate a new acquisition method that will influence the stock for 20 weeks to come once the decision of leasing is made. The cost of leasing is accounted for at once on the moment that the decision is taken to opt for this acquisition method. Leasing is an acquisition method which will mostly be used for short and medium periods of increased equipment demand.

		Description	Value
Lease period	=		20 Weeks
Weekly lease costs	=	Lease period * Lease discount * Rent	$C_{i,t,3}$
Lease Discount	=		75%

Table 6 Framework leasing

2.3.1.2 Salepurchase

Analysing how the equipment was managed at the HFG yard, different acquisition methods could be imagined to fulfil equipment demand. At HFG most equipment is of high quality and designed for professional use. At the moment, a lot of equipment is used until the point that it unusable and it has lost all its value. Once the demand decreases, the equipment, which belongs to the yards own stock, is kept and the stock is never decreasing. The only point where equipment is taken out of the equipment stock is when it is technically at the end of its lifetime. Since the economic lifetime is by definition(Dantzig, 1998) shorter than the technical lifetime it might be interesting to resell the product at an earlier stage in its lifetime. Reselling the equipment before the end of its technical lifetime seems advantageous as a market exists where lower quality equipment is used.

From the suppliers' perspective, it might be interesting to provide a company a new product and buy it back once the value decreases less. It is assumed that the decrease of value of an asset is unequally distributed over time: fast in the beginning of the assets' lifetime and slower at the end of its lifetime. A construction is imaginable were the supplier and production company agree on an acquisition method that could be called salepurchase. When equipment is acquired using this method it will be the property of the company for a predetermined period. The production company will make procurement at higher costs than a normal procurement. The supplier will agree to buy the equipment back after a defined period under certain conditions. The supplier will be ensured to get the product back after a period in which the asset has lost most of its value. The price for which the equipment is resold is determined in advance. This acquisition method is interesting for equipment that is needed for specific projects after which it is not used again. The supplier is in a better position to find a new user for the equipment that would otherwise remain unused by the production company. The production company needs to pay the maintenance for the time in which they have the equipment in ownership.

The costs of the salepurchase acquisition method is composed in the same way as normal procurement but the initial procurement price is multiplied with the difference in percentage of the increased procurement price and the resale value. In this research it is assumed that the period after which the equipment is returned is 40 weeks and procurement price is 110% of the normal purchase price. It is assumed that a sale value of 30% of the normal procurement prices is a reasonable assumption to perform the calculations with. The salepurchase acquisition method seems to be most interesting for medium and long term increases of equipment demand.

		Description	Value
Salepurchase period	=		40 Weeks
Weekly salepurchase costs	=	Procurement variation * Procurement + Yearly maintenance Costs –Maintenance costs of first t weeks	$C_{i,t,4}$
Procurement variation	=	Increase procurement costs – Sale value	80%
Increase procurement costs	=		110%
Sale value	=		30%

Table 7 framework salepurchase

2.3.1.3 Resale

In the same line of reasoning as with the previously defined acquisition method, it seems interesting to resell equipment that is already owned by the company. This concerns equipment that is procured in the past or equipment for which a procurement decision was taken in the studied calculation period. Adding a new dimension to the acquisition strategies seems worth integrating in the PEMS once the quantity of unused equipment has been acknowledged (appendix IV). Normally there are no direct costs of not using equipment. Not using equipment might have a financial consequence that is called cost of opportunity(Brealey et al., 2006). In the situation of equipment we might perceive opportunity cost it two different ways.

- Financially all equipment needs capital to be purchased and for unused equipment this capital could be used to generate interest with the bank or an acquisition could be made that generates a better Return on Investment.
- Practically the unused equipment could be rented out towards a different production company, which performs similar activities. Renting the equipment out to such a company would generate income. This is an opportunity that is unused at the moment.

Though the two ways of perceiving cost of opportunity might be realistic they remain theoretical and are hard to realize in practice. It would be possible to realize the generation of revenue out of the cost of opportunity but that would require a lot of time and more in-depth knowledge to be executed. In case that it is understood that unused stock is undesirable there would already be a noticeable improvement in attitude within the PEMS. To make it possible to realize cost reduction and avoid having unused equipment the possibility of reselling equipment should be introduced. The introduction of this acquisition method would mean that costs of opportunity are no longer neglected.

The introduction of the possibility of reselling equipment would mean that the equipment stock is capable of fluctuating in two directions: increasing and decreasing. For practical reason it will also refer to reselling equipment when using the term acquisition methods from this point on in the report. Taking into account the cost of opportunity, the resale strategy is assumed to have negative cost or in other words generate revenue. The amount of revenue this acquisition method generates does depend on the condition in which the equipment is. The determination of the exact condition is not directly relevant to this research. It is assumed that on average the resale value is 10% of the gross procurement price. The 10% seems a reasonably low value and limits the influence of the resale method. If the influence of the resale acquisition method would be too important on the total costs of the management strategy the latter would become less accurate as the input of the resale value is not very accurate in itself. Once some equipment will be sold, the resale percentage can be determined with more accuracy based on a database of made sales and the resale option might be used more.

		Formula	Value
Resale value			10%
Resale costs	=	-Resale value* Procurement	$C_{i,t,5}$

Table 8 Framework resale

2.3.1.4 Updated model

The newly introduced acquisitions methods can be translated into the formulation of an adjusted ILP-model to determine the optimal acquisition costs. Some additional inputs are defined, new variables are defined and new constraints are specified. The variable end stock $S_{i,53}$ has not been defined at this point; this variable enables the user of the solver to avoid reselling all owned stock. This means that at the end of the horizon the company will still poses a stock of its own. The model would otherwise sell all the equipment in the last week as this would generate extra revenue. The input end stock is only introduced at this stage as it was not necessary in the first model. There was no possibility of reselling equipment. Further analyses of which actions are taken at the end of the planning horizon are elaborated in paragraph 5.2 of part III. The new variables are assembled in Table 9 and they are additional to those already specified. Most of the variables and sets seem logically deducible from newly introduced acquisition methods. To optimize equipment acquisition the following extra description of the optimization problem can be given:

The set that describes the different acquisition methods K is extended in this model with three new methods |K|= 5; k=3 corresponds to leasing equipment, k=4 corresponds to salepurchasing equipment and k=5 refers to reselling equipment. As outlined another special value for the stock is introduced: $S_{i,53}$. It describes the quantity of each type of equipment that the user seems necessary to posses at the end of the planning horizon. Finally the variables alpha and beta are introduced to describe the assumed duration of the lease and salepurchase periods, these acquisition methods increase the stock during that period.

Sets	Description	Value	Variable	Description	Value
K	Acquisition methods	Lease 3	α	Lease period	20 weeks
		SalePurchase 4	β	Sale purchase period	40 weeks
		Resale 5			

Table 9 Used parameters improved ILP

The adjusted constraint (2) and a newly introduced constraint (4) and (5) can be formulated mathematically as follows:

$$S_{i,j} = S_{i,j-1} + \sum_{k\in K} X_{i,j,1-4} - \left(X_{i,j-\alpha,3} + X_{i,j-\beta,4} + X_{i,j-1,1} + X_{i,j,5}\right) \qquad \forall_{i\in I, j\in J, k\in K} \qquad (2)$$

$$S_{i,53} = S_{i,52} - \left(X_{i,53-\alpha,3} + X_{i,53-\beta,4} + X_{i,52,1}\right) \qquad \forall_{i\in I, j\in J, k\in K} \qquad (4)$$

$$S_{i,53} \geq endstock \qquad \forall_{i\in I} \qquad (5)$$

Or in words:

(2) The stock for a certain type of equipment in a certain week is built up by the stock of that specific type of equipment in the previous week.

- **Added to that are all the acquired equipment in that week for all acquisition methods but resale.**
- **Subtracted from that are all the rented equipment of the previous week, the leased equipment that was acquired alpha weeks earlier, the salepurchased equipment acquired beta weeks earlier and the resold equipment.**

(4) For all equipment types the stock in week 53 equals the stock in week 52 minus all the rented equipment of week 52, the leased equipment that was acquired alpha weeks earlier, and the salepurchased equipment acquired beta weeks earlier.

(5) The stock in week 53 is equal or bigger than the determined endstock

The new constraints do not significantly increase the complexity of the problem and therefore the same software can be used to solve the new ILP.

2.3.2 Allocation

In the current situation some of the equipment is given directly to the workers who are going to use them while equipment needs to be shared between workers. By providing every worker with sufficient equipment the goal is to not waste time and provide everybody with all the resources they need. In the situation that equipment is directly given to a worker it becomes his responsibility to maintain and use it properly and replace the consumables in time. In case of failure the worker needs to make it known at the AFD that can repair it. The certifications are administered by the AFD and they are updated once the equipment is brought to the AFD. In case equipment is never brought to the department for repair, the certification might become outdated. To be able to guarantee the good care of the equipment toolboxes are provided in which the equipment can be locked to ensure that other workers do not use personally assigned equipment. Having the equipment locked up in a toolbox lead to a lack of control over the equipment. The strategy of allocating equipment to all workers is currently applied for the types of equipment that in the table below have the allocation factors 1.

Equipment type	Allocation	Equipment type	Allocation
Disc cutter*	1	Distribution unit light	0.67
Pin toll*	1	Distribution unit mixed gas	0.67
Mig welding machine	0.67	Distribution unit Natural gas	0.67
Tig welding machine	0.67	Distribution unit compressed air	0.67
Tack welding machine*	1	Mobile distribution unit	0.67
Gouging machine	0.67	Distribution units	0.67
Welding vapor extractor	0.67	Forklift truck	0.67
Cutting torch*	1	Welder Toolbox*	1
Beetle portable gas cutter	0.67	Fitter toolbox*	1

Table 10 Allocation factors

The other types of equipment are transferred between the workforce at the end or beginning of the shifts. In most cases this is because the equipment is not displaced very easily and the next team carries on with activities where the first team has stopped. The fitness of the equipment is no longer the responsibility of a specific worker. The team leaders and foreman have to check whether the equipment can be used safely and its certification is up to date.

The allocation factor of an equipment type has an impact of the quantity of equipment required. For those types of equipment that are allocated to all workers it implies that at any shift a large quantity of equipment remains unused. The quantity of unused equipment equals the number of workers that are not working at that moment. During the day shift which is the shift during which the largest number of manpower is present on the yard the estimation is that 33% of the 100% allocated equipment is unused as only 67% of the people are at work. In a situation of a shortage of equipment workers might have to hold their activities while there is a large number of equipment that could be used but that is locked in their colleague’s toolboxes. This method of management does create the situation were equipment is abundantly available and can still seem to be in shortage. This means that the total number of required equipment can be reduced, since not everybody does need its equipment at the same moment.

The adjustments made in this step consist of changing the allocation of all types of equipment into 67% and additionally the change of the allocation factor to 33%. Reducing the allocation factor to 33 % means that there would be 3 different 8-hour work shifts in which an equal number of people are working. Taking into considerations the extreme allocation of 33% gives an idea of what the total impact of reducing the allocation factor could have on the costs of the PEMS. By increasing the number of shifts or by dividing the workforce more equally over the shifts a reduction of the costs might be realized but to implement these changes some increased expenses are made to let people work overnight. The model remains the same after changing the allocation factor as it has no impact on the manner the optimal acquisition method is calculated. As a result of this modification only the demand, which is an input, is modified and this has an impact on the expenses necessary for providing equipment. The increased implementation expenses are not detailed in this part of the research but they are analysed in the realization part.

Part III Results

Having described the calculation models, the results can be obtained and used to make a comparison of introducing new calculation techniques or modifying the framework. The results formulate an indication of the costs which is the parameter on which the evaluation of the performance of the PEMS can be based upon. Minimization of the costs can only be measured if first the current costs are determined. Once this is done, there is a reference point from which an analysis can be made about the quality of the improvements. From this starting point the result of step-by-step adjustments can be made to the calculation of equipment costs to observe the impact each modification has. The first result of the adjustments to be observed is the introduction of ILP as a tool for acquisition management. Once this calculation technique is introduced other result can be observed of the improvements made and it could be determined which changes have the biggest impact on reducing the costs. The determination of most influential parameters is the outcome of this part of the research and they will form the basis of the changes that are to be made to equipment management strategies.

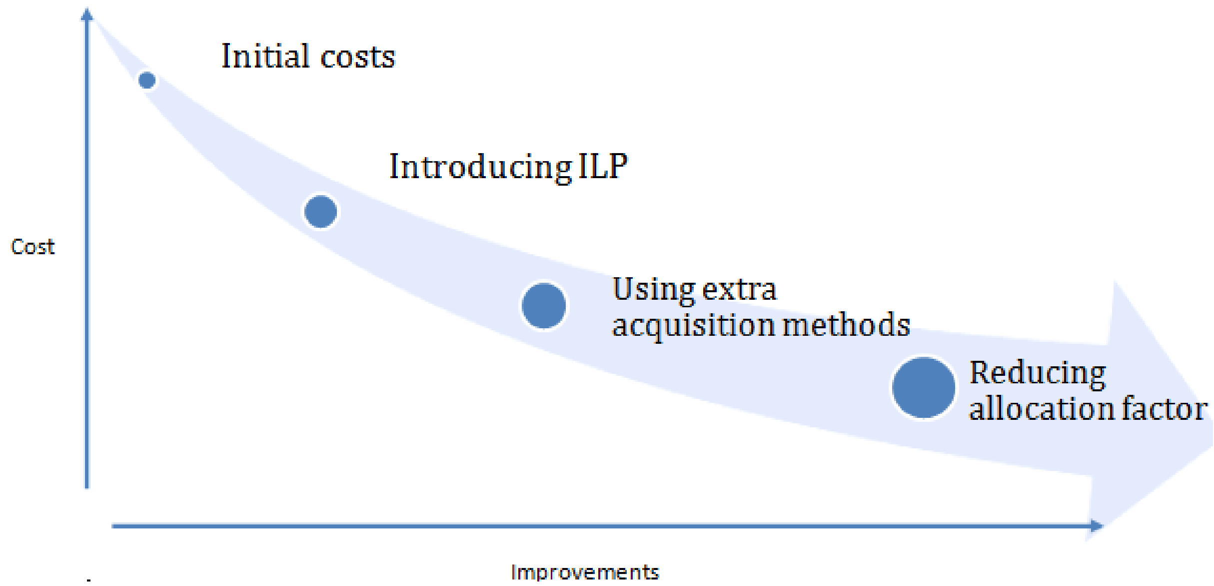

Figure 11 Improvements calculation process

3.1 Initial forecasted management costs

To obtain the current costs of equipment management, the most evident way is to add up the expenses made for acquisition equipment in the last year. The costs that are made in 2013 for equipment $C_{initial1}$ are 218,580 Euros. Normally this would give a good idea of what expenses are made yearly to provide equipment. In practice, the workers were not provided with all the equipment they need, especially disc and pin tolls are not provided sufficiently. The team leaders can make a request for more equipment but if there is no budget available to acquire it then the work needs to be executed with limited resources. Adding up all the made expenses in one year does not give an understanding of the real expenses. Presuming, that the team leaders request the quantity of equipment required to perform the activities optimally. This would mean that the equipment management costs should be higher than $C_{initial1}$ to have an optimally functioning work process. Once using a mathematical model the calculations provide the total costs of equipment management with all workers being allocated the equipment they require. To make a proper comparison between an adjusted PEMS and the current situation the costs of providing sufficient equipment must be determined.

To tackle the issue of the current costs $C_{initial1}$ being based on only the renting of a part of the equipment the total missing quantity of equipment is determined for each week using the formula Equipment demand in week – Start stock. Adding this up to a yearly total an insight is provided in the number of required weeks of rent for that type of equipment. The costs of renting all this equipment is determined by multiplying this number with the rent cost of that equipment type. This adds up to a total of 674,615 Euros that is considered as the variable $C_{initial2}$. It can be observed that the costs increase with more than 300% if every worker would be provided with all the equipment that he requires if renting is used as acquisition method.

The outcome of this investigation into the current expenses is that it is not known exactly what the costs of the current PEMS are. At this stage it has been determined what the range in which the actual costs of providing equipment must be. The lower bound is determined by the costs made for this year of renting part of the required equipment. The upper bound is fixed by the estimated costs that would be made if all the missing equipment would be rented and every worker would be provided with sufficient equipment to work optimally.

Figure 12 illustrates the range in which the analysed costs can be found. In the next stage ILP is introduced to know what the costs would be if a solver would determine the optimal acquisition method.

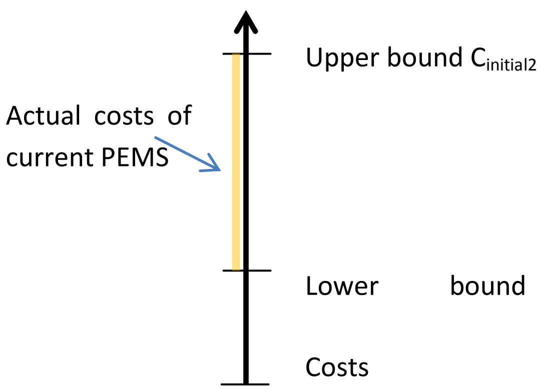

Figure 12 Cost initial forecasted management structure

3.2 Introducing ILP

With the use of the AIMMS Software package all information about the concerned optimization problem can be processed into an ILP. A procedure is programmed to run the calculations necessary to solve the ILP. The software is capable of reading the information from a spread sheet, solves it and then writes the outcomes in another spread sheet. Using the created procedure, the calculations are simplified to provide input information about demand and cost acquisition. Performing a small number of computational actions this information is processed and provides the results using the CPLEX solver. The solution of the procedure consists of a set of values for all variables X, S, and of a total cost estimation Z. The variables X can be used to know when to make a certain acquisition decision if the optimization technique was to be applied for equipment management. An overview of the values of X can be found in Appendix IV and in the research only the values of Z are analyzed as this represents the cost performance of the PEMS with a given modification.

To obtain a solution a run of the procedure is performed in which the demand for equipment based on the workforce planning of 2013 is used. The cost of acquisition methods is based on the analyzed price estimations and the start stock determined by the current stock based on de description in the framework and inputs. The estimated cost C_{opt1} that are made to provide the necessary equipment using ILP to determine the best acquisition decisions is 338,320 Euros. If placed on the same axis as the one used to symbolize the initial cost for equipment management the figure below is the result.

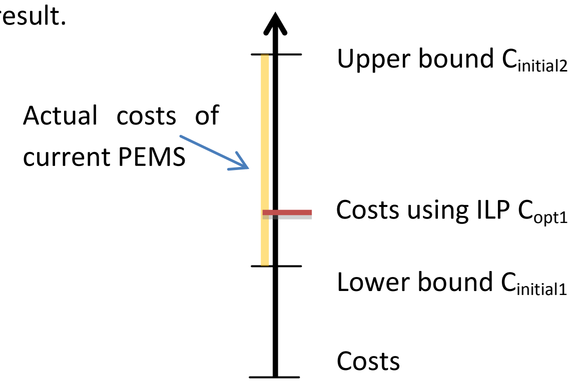

Figure 13 Cost introducing ILP

It can be analyzed that using ILP to determine the acquisition of equipment sets the total costs of equipment management to the lower side of the range of the current made costs. While the lower bound of the current cost estimation is still smaller, using ILP will provide all workers with sufficient equipment.

Some resources are necessary to apply ILP in the PEMS. One of them is that the planning of the workforce, the equipment stock and gross equipment prices are up to date and need to be reviewed frequently. In appendix V the necessary resources are further analysed to enable a complete analysis of the implementation of this modification in part IV of the main report.

Using ILP has a significant impact on the costs of how equipment is acquired and it provides in a fast way the optimum between renting and procurement. More adjustment can be made to further improve the PEMS. These modifications are the subject of the next steps.

3.3 Using extra acquisition methods

In the next adjustment a new procedure is set up in which the costs of leasing, salepurchase and sales are included in the model and an end stock is introduced. The cost necessary to operate the PEMS once ILP is used that integrates leasing, salepurchase and resale acquisition methods are respectively 294,534, 279,582 and 275,981 Euros. The effect of introducing a new acquisition method, however, also influences the introduction of the next one. This means introducing the acquisition in a different order will change the impact that each acquisition method has individually on the PEMSs' costs. It is considered that all acquisition methods are introduced at once and the new costs of managing equipment is C_{opt2}, equals 275,981 Euros. The improvement of the ILP model does mean an absolute improvement of 62,339 Euros.

The figure below gives an indication what the consequences of the adjustments are relatively to the previously made calculations.

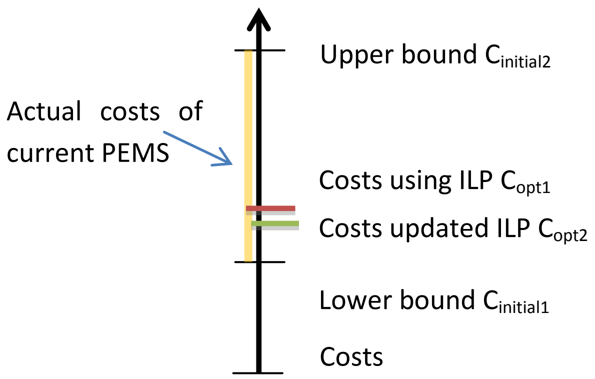

Figure 14 Costs updated ILP model

Relatively the improvements do not reduce the cost related to the equipment management much. However, to implement these new measures very few new resources are needed. The procedure is only adapted a little by adding variables to the ILP-model. Once the user understands these modifications the implementation costs are similar to the one made in the previous step.

In comparison with the previous step however it becomes more important to take action as soon as the solver determines the decision of renting or reselling equipment. As the equipment stock has become more dynamic with these new adjustments the cost estimations only become realistic if measures are implemented to realize these dynamics in practice.

In this first step of improvements, focus is put on adjustments made on the manner in which equipment is acquired. This set of adjustments contributes to the improvement of the cost optimization of the PEMS. Another objective of the research is to also look how the available equipment could now be allocated better to each worker. These improvements are the subject of the next step.

3.4 Reducing allocation factor

Having been able to observe the result of optimizing acquisition techniques, some, additional improvements have been modelled to the allocation of the equipment. The costs of the PEMS needed if equipment is managed with an allocation factor of 67% are C_{opt3}. The value of that variable is 49,967, which means that the influence of changing the allocation of equipment has an ample impact on the costs of the PEMS. If the allocation factor would be further reduced to 33% the cost of providing additional equipment would become 1,439 this value is referred to as C_{opt3}. Figure 15 gives an indication what the consequences of the adjustments are relative to the previously made calculations.

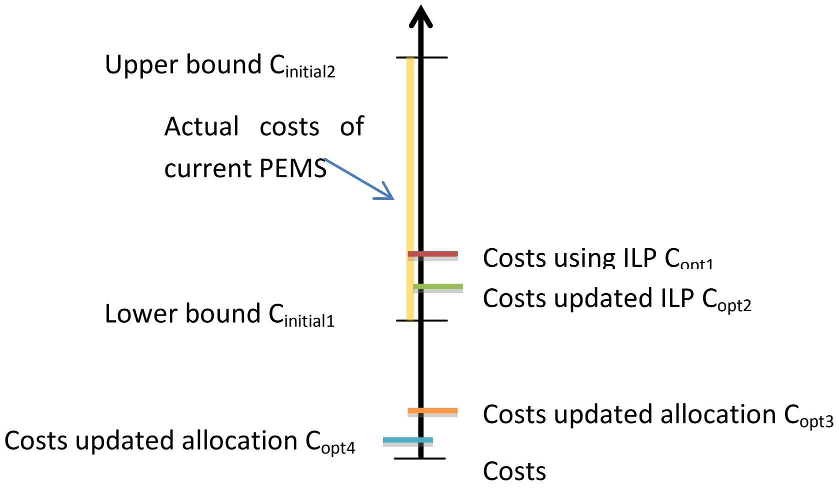

Figure 15 Costs updated allocation

Implementing changes to allocation factor would mean application of measures that would make sharing equipment mandatory. Reducing the allocation factor to 33% could mean reducing the cost of providing enough equipment to less than 20,000 Euros. This is less than 10% of the lowest estimate of the current expenses made to provide equipment. The calculated expenses do represent the cost of providing additional equipment to that which is already the property of the company. In case the costs would be reduced to 0 % of the initial forecasted costs this would mean that the demand of equipment could be covered with all the equipment in the start stock.

At this stage, all the adjustment to the PEMS are introduced and the effects have been calculated. In the next step the adjustments are compared with each other and it is analyzed what adjustment would be eligible for practical modifications in management processes.

3.5 Implications

In this final step the modifications to the management strategy are assembled and compared. The adjustments are regrouped into two modifications that are eligible to be implemented into management strategies. Further attention is also given to the sensibility of the input parameters: planning interval and owned equipment stock. The adjustments are so far only tested based on planning of equipment demand based on the workforce planning of 2013. The calculations are now repeated based on a workforce planning of 2014 (Appendix I).

3.5.1 Costs

One consequence of using ILP is that it entails using more equipment since all workers will be provided with the equipment they require. In the current PEMS it has been acknowledged that not enough equipment was available. In order to make a realistic comparison with the other management structures an estimation of the initial forecasted management costs is calculated. To be able to make a comparison between management structures an estimation of the initial PEMS needs to be made. This estimation C_{opt0} is based on the average between the cost made in the initial forecasts $C_{initial1}$ and the cost that would be made if all non-available equipment had been rented $C_{initial2}$. This average value is an indication of what would be the costs if more/sufficient equipment were provided as the team leader and workers had estimated to be necessary.

Using the estimated costs for providing enough equipment C_{opt0} as reference point, we can evaluate that using ILP to make acquisition decisions could reduce the expenses to provide equipment in 2013. The reduction is 24% of C_{opt0} if the same acquisition methods are used. In case three new acquisition methods are introduced the expenses could be reduced with an extra 14%. The initial forecasted expenses are still lower and to reduce the expenses below the current expenses the allocation of the equipment needs to be modified.

In case that all equipment has an allocation factor of 67% the total costs would become less than the current costs. This modification realizes an extra cost reduction of 51% for providing additional equipment compared to C_{opt0}. Implementing ILP and reducing the allocation factor makes it possible to achieve the objective of providing more equipment for less costs. In other words, with this set of adjustments the AFD department will be able to provide enough equipment for every worker while needing fewer expenses. Table 11 summarize the absolute and relative impact on the costs of PEMS of the adjustments.

	Extra costs 2013			Extra costs 2014	
Initial forecasted costs	218,580	59%			
Estimation C_{opt0}	446,598	100%			
ILP version 1	338,320	76%	100%	805439	100%
ILP version 2	275,981	62%	82%	668701	83%
Allocation 67%	49,967	11%	15%	290118	36%

Table 11 Impact of adjustments on costs

In the last adjustment the allocation is only reduced to 67% since reducing it further would have a far bigger and more complex influence on activities. The additional cost reduction which could be realized might not be justified due to the larger implementation costs. Reasonably an allocation factor of 50% should be considered as the maximum realizable. Beyond that point reducing the allocation factor would imply that nightshift needs to be implemented. This is a policy adjustment which is considered too big and complex. Realizing a reduction of allocation further than 67% would require involvement from workforce planners. Knowledge necessary to make such adjustments goes beyond the knowledge expected for equipment management.

In Table 12 the results of the costs calculations based on the workforce planning of 2014 (Appendix I) are summarized. As the costs that would be made in 2014 using the initial forecast method cannot be calculated the comparison can only be made based on cost estimates once ILP is used. With the data of 2014 introducing the new acquisition methods has relatively the same impact on expected costs of 2013. The influence of modifying the allocation factor has more impact with the planning of 2013 as extra reduction of 65% of the costs can be realized, which is significantly more than the extra 50% reduction in 2014. Making the adjustments on the PEMS does have an impact on both planning horizons and large savings which could be realized. The absolute savings that could be realized by using improved ILP and changing allocation to 67% could be more than 390,000 in 2013 and almost 500,000 in 2014. Figure 16 illustrates the magnitude of the influence the adjustments make on the estimated costs to provide additional equipment.

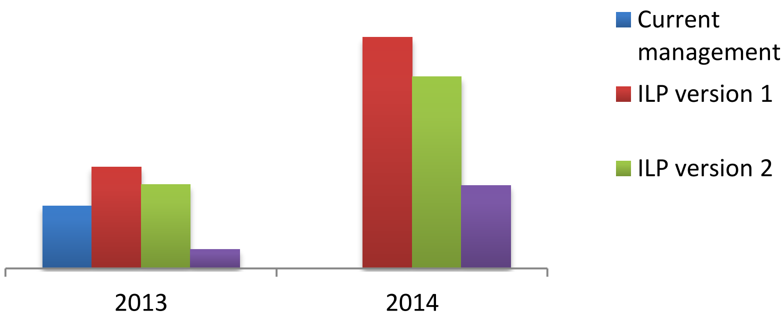

Figure 16 Absolute extra costs

Figure 16 points out that reducing the allocation is the adjustment that has the biggest influence on the cost performance of a PEMS. In the next part focus will be put on how these adjustments can be realized and at which costs they can be implemented. It does not seem necessary to describe the realization of each improvement of the PEMS. The adjustments that are taken into account from this point are regrouped into two sets of modifications:

- Using ILP to determine the optimal strategy of acquisition. This regroups the introduction of ILP in equipment management and the use of extra acquisition methods.
- Allocating the equipment to only the people that are on the work floor considering that at most 67% of the personal is at work at once.

The consequences of two proposed adjustments are translated in possible policy and management modifications in the realization part.

3.5.2 Quantities

Analyzing the results of the new calculation model made the sensibility of some parameters clear. The planning horizon and the stock in ownership have been kept equal where in reality these are parameters that could fluctuate. This paragraph describes how the dynamics of these parameters are dealt with in order to properly understand the working of the calculation model.

Until this point the stock at the beginning and end of the planning horizon have been kept equal since the model would otherwise automatically sell equipment at the end of each planning horizon. This does not seem the best solution since this would mean that no stock would be available for following planning horizon. For both estimated equipment horizons, 2013 and 2014, there is equipment, which seems to remain unused (appendix IV). Deducing this unused equipment from the necessary end stock the model would be able to resell some equipment at an optimal moment in the planning. This leads to the idea that there exists an optimal in the quantity of stock owned.

When reducing the end stock quantity there would be an amount in the planning interval were no equipment remains unused. The blue arrow in Figure 17 points out this point where all equipment in stock is used at some point of the planning interval. At this point the management costs are lower than if it is chosen not to diminish the stock, this is due to the revenue generated by the resale. The figure represents the link between costs of equipment management in relations with the owned quantity of stock.

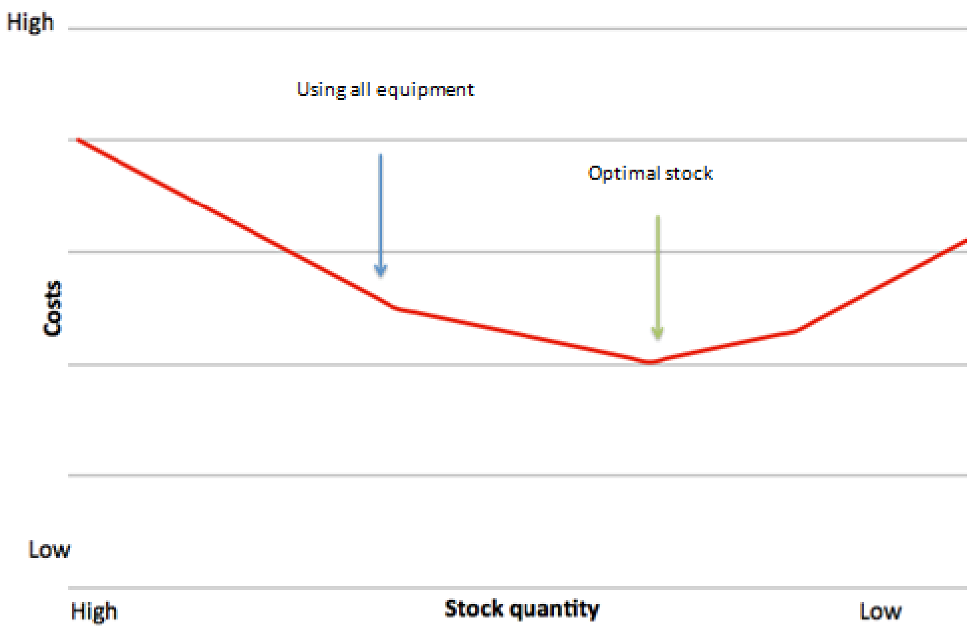

Figure 17 Optimal stock

In the first part of the graph (until the blue arrow) the cost are decreasing because equipment can be sold without consequence. The elimination of the costs of opportunity of this equipment mainly concerns the unused equipment. From that point until the next, pointed out by the green arrow (optimal stock) the costs keep decreasing. This is due the fact that some owned equipment is only used a few times. The frequency of use is so low that it is more interesting to rent equipment for these occasional uses than to keep the equipment in ownership. The equipment can be sold and the revenue would cover the extra rental costs. At some point selling too much equipment would mean that the rental costs do exceed the benefits of reselling. This happens at the moment pointed out by the green arrow. Beyond this point the costs are increasing again and the point of optimum minimum end stock has passed.

Running the calculation model for all possible quantities of stock could determine the quantity of optimal owned stock. This would require a higher-level optimization problem that cannot be realized with the currently used calculation techniques. When analysed in perspective, the effects of such precise calculations are not worth the extra research and the quantity of stock pointed out by the blue arrow is sufficiently accurate. Reselling only the unused equipment would seem an estimation that does give a fair indication of the optimal quantity of owned equipment. The assumption that using this quantity is precise enough is based on the uncertainty of the equipment demand. The determination of the optimal quantity of stock with more precision can only be done if the equipment demand is more precise.

The calculations of equipment management cost are based on the assumption that the planning horizon will come to an end, which means that some acquisition methods are more frequently used at a certain moment in the planning. Procurement for example becomes less interesting in the last weeks of the planning horizon. This deviation from realistic calculation will in practice be corrected once the input data is updated frequently. This means that in reality the end of the planning horizon will never be reached, as calculations will always be based on prediction for the coming 9-12 month if updated quarterly.

The determination of the optimal stock quantity and an up to date equipment demand is integrated in the implementation of using ILP in equipment management.

Part IV Realization

Having determined important adjustments that need to be realized in order to reduce the expenses of the PEMS, research now concerns how to implement these modifications. To be able to properly implement the changes the stakeholders are analysed in order to define the best implementation strategy and acknowledge supporters and opponents of new management strategies. Besides the stakeholders other aspects (types of equipment, activities and management methods) of the environment are analysed in Appendix II to provide a full understanding of the PEMS environment. Once the setting is defined changes can be proposed to the management structure. The policy changes are described and evaluated on their costs and benefits in the second section of this part.

4.1 The equipment environment

To get an idea of the environment in which the research is executed, an analysis of the organization will help to determine which stakeholders are involved when implementing solutions. By mapping the stakeholders and the environment of the equipment management the best strategy for a successful implementation can be determined. The analysis of the stakeholders is started from the most general aspect of the company and narrowed down to the relevant stakeholders as the inquiry becomes more detailed. First, this is done by looking at the environment from the organizational structure but since most activities are executed to complete a project a second analysis of the stakeholders is done from a projects' perspective.

4.1.1 The stakeholders

4.1.1.1 Organizational stakeholder analysis

Heerema Fabrication Group is part of the Heerema group organization and the members of the company's board run its management. Some board members are also involved with the activities of the other divisions of the Heerema group. Responsible for the overall management of HFG's activities these non-executive members together with the executive members (CEO, CFO and COO) structure the board and define the overall strategies of the firm. The executive members each have responsibilities over several departments of the company. However, in the figure below only the tasks of the COO have been detailed since these are departments involved with equipment management.

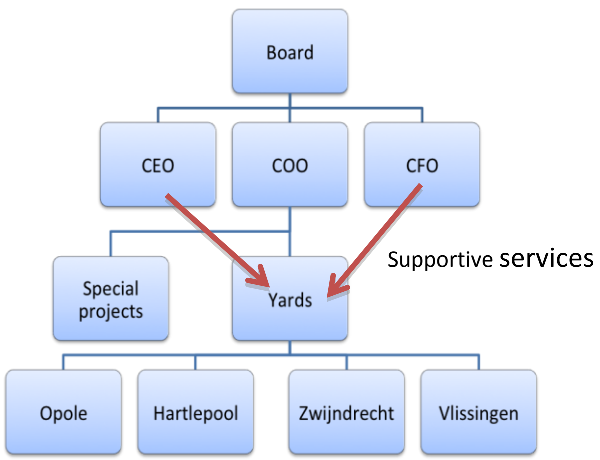

Figure 18 Heerema corporate organization (Heerema, 2013)

When we look at the responsibilities of the COO, we can see that they are divided into two types: Yards and special projects. The four yards of HFG are the locations where the products of HFG are assembled and constructed. Each yard is supported by services that are under the direct supervision of the CEO and CFO. In charge of each yard is a yard-director that is managed by the COO. The yard director is under supervision, which is the responsibility of the other executive board members. The yard is organized according to the organogram illustrated in Figure 19; it provides insight in what environment the AFD has to perform its tasks. The analysis of the surroundings of the equipment owner seems relevant for the applicability of the research's solution.The setting in which AFD operates is composed of mainly 3 departments.

- Steered directly by the Yard direction the AFD has to follow the guidelines set out by yard management and it should explain its performance to the yard director.
- The production departments of the yard provide people, materials and knowledge for a project, the AFD provides the necessary equipment. The production department is the end user of the equipment.
- Project managers outsource activities that are not part of the firms' core activities towards sub-contractors. This is done with little involvement of the other departments and in this research these activities are not further analyzed.

The PEMS is functioning with the input and collaboration of the above departments that form the environment wherein AFD manages production equipment. Changes to the PEMS will have an impact on the processes within these departments and solutions can only be found if these departments are willing to collaborate.

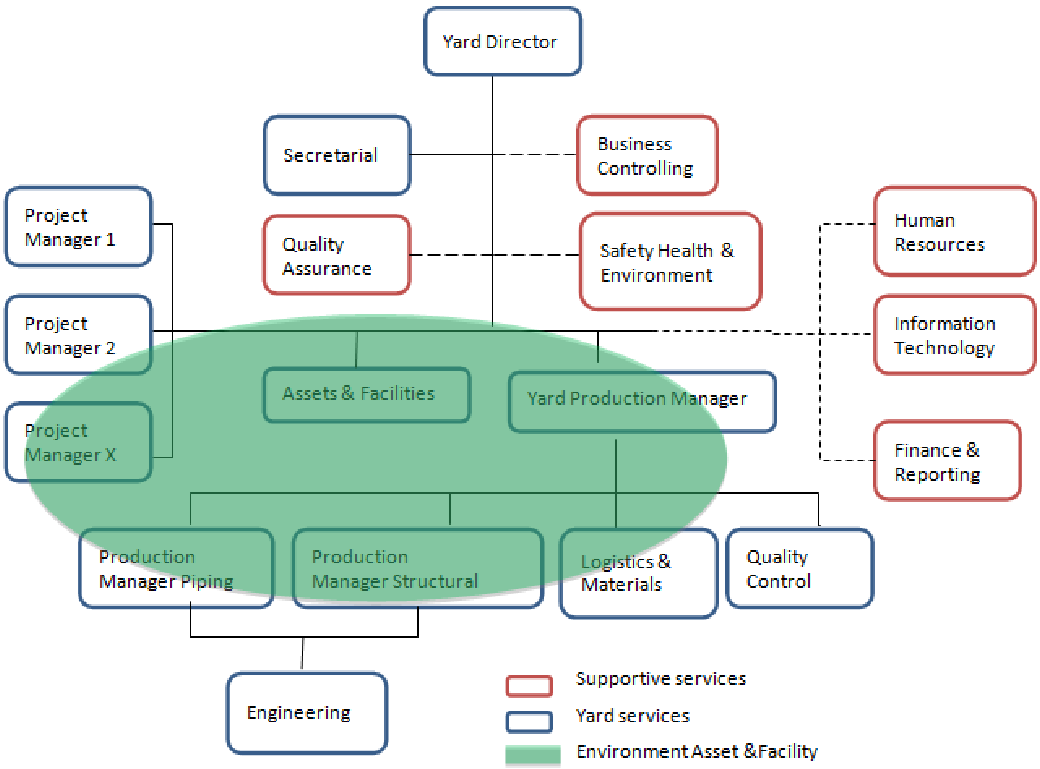

Figure 19 Heerema yard organization (Heerema, 2013)

4.1.1.2 Project stakeholder analysis

So far the analysis of the environment of the AFD has been done from an organizational perspective. The organization is set up with the objective to complete as many projects as possible. Depending on the location of the production yard these projects can be the construction of jackets, topsides or sub-components of platforms. The analysis of the environment of the AFD seems complete if it also observes the stakeholders from a project perspective. By doing so, a complementary analysis and a better application of the research solutions is ensured as the stakeholder analysis is done from two perspectives.

A project is a system of people, equipment, materials, and facilities organized and managed to achieve a goal(John, 2003). If we look at the dynamics of the project, people, equipment and materials can be adjusted on the short term and in this research we consider these facilities as fixed. The projects have to be realized with the given facilities and the project manager has to determine the optimal quantity of the other three parameters. The manager can choose to increase the quantity or quality of one parameter to influence the projects performance of time, quality and costs. These three parameters are called the projects iron triangle in literature(Atkinson, 1999).

The first parameter is the people necessary to perform the activities, the employees involved in a project consist of a large number of specialized workers. In case a project runs into delays, the project managers usually increase the number of workers in order to be able to still meet the deadline. The production department manages the people performing HFG core activities.

The second parameter necessary to fulfill a project is the required equipment that needs to be available for the workforce. The quantity of equipment only increases at the same pace as the quantity of the number of workers. It is rare that extra quantity or quality of equipment is increased without also increasing the amount or workers. The AFD manages the availability of enough equipment and its condition.

A third parameter needed to complete the project within its requirements is the needed materials. This is where the procurement department is involved in the projects. In a situation where the other resources, people and equipment, cannot be stressed anymore the project manager needs to change the materials he had previewed to use in order to still meet the projects’ requirements. If the requirements cannot be reached adaptations are made on the type of materials procured. The project manager can choose to outsource some work and procure sub-components of the project instead of making them internally. A sub-contractor will be chosen with the help of the procurement department to deliver sub components of the construction.

The analysis of the project environment is summarized in Figure 20 and shows that the environment of the AFD from a project perspective is different than an organizational perspective.

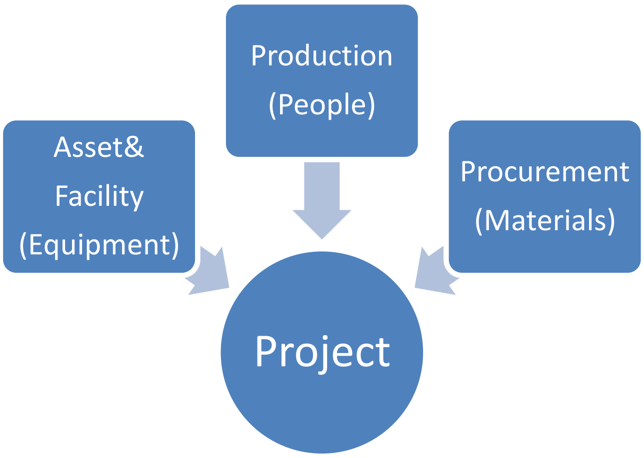

Figure 20: Project resources

Mapping different departments of the organization from different perspectives creates better insight in the stakeholders involved in equipment management. Defining the environment from two perspectives aims to avoid the misinterpretation between a theoretical and practical environment in which the PEMS operates. The stakeholders can both be used as a source of information and grounds for implementation.

4.1.2 Environment Asset & Facility

Based on the analysis made in the previous paragraph, Figure 21 summarizes the position of the AFD in its environment. The red circles illustrate the environment that would be observed when looking at the activities from a project perspective. The totalities of the circles represent all the departments that are involved with AFD such as the organization has defined it. The blue circles represent the departments that in reality might not be closely involved with equipment management.

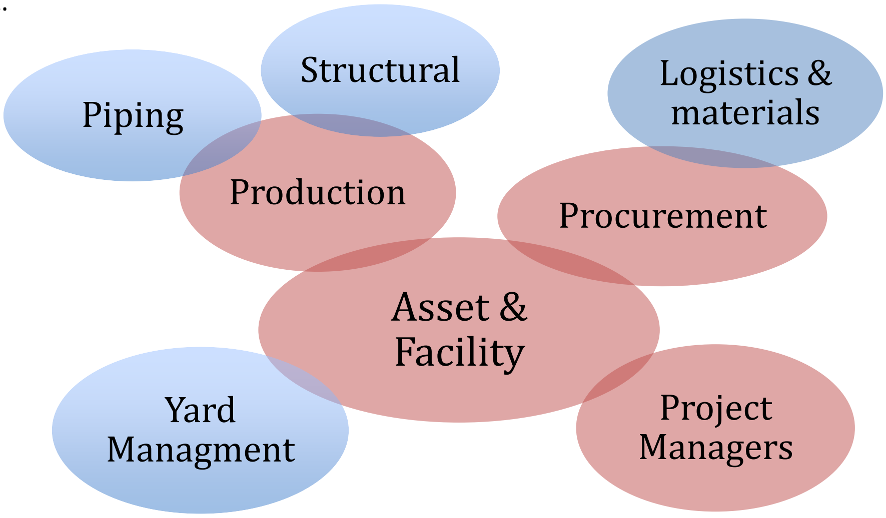

Figure 21: Stakeholders surrounding Asset & Facility

Looking at the stakeholder from the equipment aspect it is assumed that they collaborate within the area where the circles overlap. Each stakeholder has a different relation with the AFD, together the stakeholders are all responsible for a specific part of equipment management. The AFD has the biggest portion of responsibility concerning equipment and is considered to be the owner of the equipment. Having the main responsibility the AFD must ensure that the relation with other departments remains of good quality, since the collaboration has an impact on the departments' performance.

Some of the links between departments are formally defined and it is clearly known who bears which risks. In some cases, however, this is not so clear and depending on the individuals the equipment management needs to be adjusted to avoid failures. A failure is considered once equipment is not available or a large quantity of equipment remains unused. One stakeholder can cause the failure of equipment management but it always leads to frustrations of more stakeholders. Executing an analysis of each stakeholder can be useful in determining where risks of failure occur; this can contribute to the identification of where adjustments need to be made in the PEMS. All stakeholders are analyzed in appendix II paragraph 3 and as a result Table 12 is obtained which forms an overview of the stakeholder analysis.

Stakeholder	Stakeholders goal	Problem perception	Position	Power	Resources
Asset &Facility	Provide equipment within budget	Lack of control, big demand for given budget	Supportive	High	Knowledge
Procurement	Make best value acquisitions	Lack of Information	Reluctant	Low	Experience
Logistics & Materials	Providing resources on-time	Lack of equipment	Neutral	Low	Experience
Yard Management	Constrain costs	Lack of control	Supportive	High	Power, Financial
Production	Producing in time	Insufficient equipment	Supportive	High	Knowledge
Production Piping structural	Producing in time	Insufficient equipment	Reluctant	Medium	Experience
Project Managers	Delivery of project on time within budget	Inefficient work process	Neutral	Medium	Financial

Table 12: Overview stakeholder analysis

4.1.3 Power/interest grid

As a result of the stakeholder analysis we can map and evaluate each of the stakeholders based on the power and interest they have in changing the management of equipment. Once the stakeholders are mapped on the power/interest grid we can identify four groups of stakeholders each located in a different quadrant of the grid. Several studies (De Bruijn et al., 2008) propose a different approach to the collaboration with each of the different categories of stakeholders:

- The key players have high power and high interest on completing the project; they need to be more closely monitored as they can form a serious obstacle in making adjustment to an equipment management policy if they become opponents.
- The crowd as opposed to the key players has less power and interest in the project and does not form a great danger to the success or the completion of it. The proposed strategy is usually that they are monitored with a minimum effort and having them opposed is usually not considered as problematic but should be avoided in case they could be convinced easily.
- The subjects are those with high power but low interest and an effort should be made to keep this category of stakeholders satisfied. If a decision is made that does not suit them, they might gain interest in the project and become a problematic opponent.
- The context setters are usually the stakeholders with little power but a large interest. They are the ones that are most involved in equipment management but they do not have a direct influence in its decision-making and set up.

Figure 22 shows what the power/interest gird looks like if it were made for a project regarding the implementation of changes in equipment management. This grid is the conclusion of the analysis of the organizational environment and can be used to determine strategies to implement the adjustments made to the PEMS.

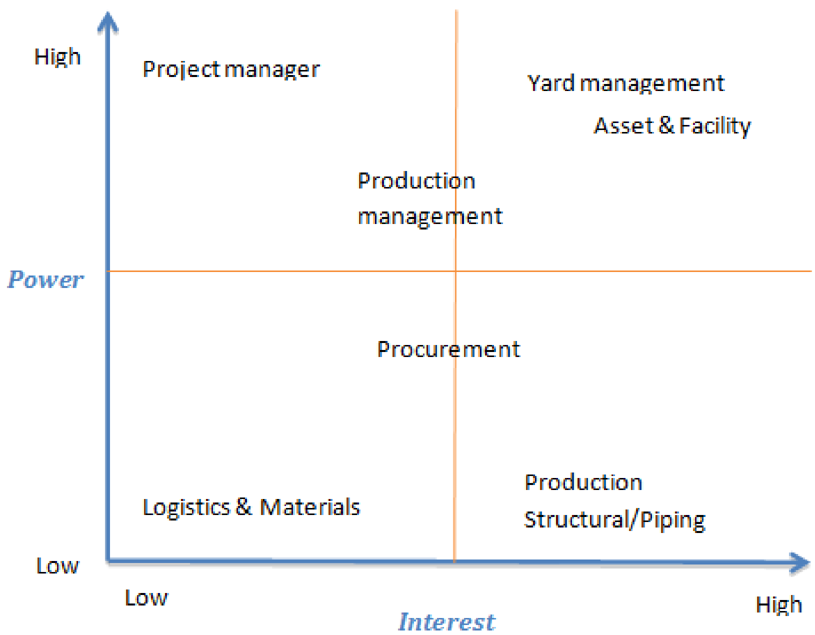

Figure 22 Power/interest grid

4.2 Changing management strategies

To make the improvement to the PEMS it was analysed in the previous part that the allocation factor should be reduced and ILP should be applied. These improvements can only be realized if calculation methods are adjusted and management strategies are changed. The changes of management strategies come with costs that should be taken into consideration when making the evaluation if the improvements are worth implementing. The changes in the management strategies are described and defined in appendix V to provide a clear idea what the intended goals of the adjustments are. In this part a quick overview is given of what the most important changes in management strategies would be. Having come across some policy changes, it appears necessary to adjust these to enable proper implementation of the new PEMS. Once, all costs are inventoried, a review can be done to gain insight into the total benefits of implementing changes.

4.2.1 Management strategies

The first adaptation that has to be made is the introduction of ILP, by installing a new procedure in the company's cost calculation structure. To enable the correct functioning of the ILP it seems necessary to start working with internal cash flows to administer the equipment exchanges and ensure the dynamics of equipment management. Besides the implementation of these two strategies the reduction of the allocation factor should be realized. New policies on where and how equipment is stored should be implemented to enable the reduction of the allocation factor.

Additionally it seems necessary to create a network to make reducing the allocation factor realistic. Some of these modifications are elements of lean manufacturing; another policy that could be implemented to make consistent improvements to the PEMS. The changes are to be applied into new continuous operational processes while they might also mean modifications to existing processes. Each modified policy requires resources and involves different stakeholders. The stakeholders need to be approached to enable the correct implementation of the new management strategies. Table 13 summarizes the implementations made, described in Appendix V, and gives an insight into what the costs and benefits of each change in management strategy. It also outlines the stakeholders needed to be involved.

Management strategy	Resources	Benefits	Impact
Using ILP			
	Quartile planning updates		Production department
	0.2 FTE during 6 months		AFD
	New acquisition methods		Procurement department
		Being provided enough equipment	Production structural/piping
		Determining optimal acquisition method	AFD
		Less costs needed for PEMS	AFD
Total	19,000 Euros	135,000-170,000 Euros	
Reducing Allocation Factor			
	Approx. 2-3 FTEs		AFD
	Handling desks		AFD
	Storage area		AFD
	5S storage board		Production department
		Implements lean manufacturing	AFD /production department
		Enough tools	Production departments
		Less costs needed for PEMS	AFD
Total	85,000-110,000 Euros	220,000-360,000 Euros	
Internal cash flow			
	Approx. 0,2 FTE per department		All departments
	Administration system		Yard management
		Better functioning PEMS	AFD
		Better allocation of budget	Yard management
Focus on workforce			
	Better equipment		AFD
	Reselling equipment		Procurement department
		More effective work process	Production department
Internet of Things			
	New administration system		Yard management
		More control on equipment transfers	Yard management
		Reduce allocation costs	AFD
Lean manufacturing			
	New work procedures		Yard management
		Safer work environment	Yard management
		Reducing allocation factor	AFD
		Increased quality credibility	Yard management

Table 13 Implemented management strategies

4.2.2 Policy changes

Implementing several new ideas or strategies, in the policies and processes of the HFG yard, has the goal to improve the PEMS. To do so it is not only important to make temporary adaptations but the new PEMS need to be integrated continually in the work process. A few operational processes need to be changed/ designed to enable a correct use of the new PEMS and better possibilities of successful implementation. The following policy adjustments are recommended:

As an input, the standardized quantity of equipment has been determined and translates the workforce planning into an amount of equipment required for the workers. Once the changes are made it can be analysed if the quantity of equipment is sufficient to cover the demand of the workers or if they have too few/much equipment. The result of such an analysis can be taken into account when reconsidering the norms for provided equipment per worker. The most effective quantity of equipment per worker needs to be determined in a collaborative manner between production departments and AFD.

If the model is updated each quartile, a resale decision would only be made if equipment is not used for a longer period of time. A lot of equipment will never be sold, renewing the equipment might, however, prove to contribute to the effectiveness of the use of equipment. It seems interesting to force reselling equipment in order to own newer and more equipment. The benefits of such a renewal are hard to determine as they only concern possible improvements that are dependent on the workers themselves. Working with newer equipment can have the following advantages:

- Increase the workers' efficiency; as he works with tools that are more powerful the activities are executed quicker and with better quality.
- Increase the workers' motivation to work at HFG yard instead of a competitor that supplies lower quality equipment. There is a shortage of technical workers in the production industry and fitters and welders are scarce, a lot of workers are recruited abroad. This solves the issue of having enough workers but creates another issue that is the quality of their work. It can be understandable that good workers have the possibility of choosing where they want to work. The choice they make might for a big part be based on the salaries they receive. Supposing that the salaries do not differentiate much, providing better equipment could be a reason for workers to be willing to work at HFG. This could place the yard in a position where it can employ the best workers which would have an impact on the final quality of the construction.
- Newer equipment is in a better condition than older one and this could motivate the worker to be more aware to handle the equipment with care. This could also impacts the workplace in which the worker operate and contribute to a more organized work process.
- Motivating the worker, as they seem to be treated with more respect if they are provided with good equipment instead of old equipment.

As stated before, the benefits above are only hypothetical improvements and they cannot be substantiated with facts or numbers. The impact of reselling equipment to work with better equipment can only be determined hypothetically. Reasoning the other way around, the arguments can seem to be of the same quality. Keeping equipment in ownership as long as possible might seem cheap if only the expenses made for procurement are considered. In this line of reasoning the decreasing effectiveness of the worker, the increasing operational cost and the degradation of safety are not taken into account. The best renewal policy has to be somewhere between continual and sporadic renewal.

The changes that affect the continual work processes do have an impact on the environment of the workers of the production floor. In the current situation all responsibilities and decision making is done by management. This creates a situation in which workers do not take any decision and put all responsibility to the team leaders or managers. In an approach where the organization of the workplace is addressed by only involving managers the PEMS will not improve. Giving responsibility to the workers by linking the workers with the equipment that they use should improve the handling of the equipment and their responsibility awareness. In case of a lack of care of the handling the worker should personally have to justify why he did not handle the equipment properly. Putting responsibility back on the person who uses the equipment does not only increase the possibility to take action towards correct handling of equipment, it is also suggested that they will behave more professionally. If employees are provided with more responsibility research (Hackman and Oldham, 1976) has proven that the responsibility given will positively correlate with the motivation, discipline and responsibility that an employee take to work.

Increasingly complicated structures of decision making cost more money than providing employees the possibility to make decisions up to a certain budget (Ferriss, 2011). The costs of time and information transfer for small value decisions does not justify the complexity of the decision making structures that are currently in place at HFG. In this structure a lot of time is required from department managers to make insignificant decisions. For example the necessity of the service/product should not create discussion between a production worker and an employee of the AFD. The employee from the AFD only makes the product/service available that the team leader requests. Whenever the project manager's esteems that excessive costs are made for procurement of products/services the people that made the request for using products/services can be addressed with the use of the newly introduced management strategies.

Policies	Benefits	Owner
Evaluating norms	Better equipment requirement predictions	AFD
Newer equipment	Increase equipment efficiency	AFD
Update work planning	More reliable equipment forecasts	Production departments
More awareness/ responsibility for production workers	Safer work environment	Production departments
Less managerial involvement in low value decisions	More employees commitment	Yard management

Table 14 policy changes

4.2.3 Review

To be able to improve the equipment management the following measures have been defined to seem worthy of implementing;

- Using ILP.
- Reducing allocation.
- Creating internal cash flows.
- Focussing on workforce.
- Creating an *internet of things.*
- Using lean manufacturing.
- Continual renewal of equipment and requirement standards and give more responsibility to the workers.

The impacts of the first two measures are best substantiated as they are the measures where costs and benefits have been determined using precise calculations.

- Using ILP will reduce the equipment costs by 15% which, with the studied equipment demand, would mean between 135,000 and 170,000 Euros of yearly savings. This can be done at an investment of approximately 20,000 Euros in the first year and 15,000 in the following years.
- Diminishing the allocation factor for all equipment to 0.67 or transferring all equipment between shifts. The benefits would reduce the equipment management costs further with at least 60% or with the studied data between approximately 220,000 and 360,000 Euros yearly. The cost for implementing such an adjustment in management policy would approximately be between 80,000 and 110,000 Euros in the first year.

These two adjustments are evaluated on approximations that are rounded down in case of benefits and rounded up in case of costs. This increases the reliability of the evaluation as the cost estimations are made with some uncertainty. The total benefits made by introducing these two measurements once the maximal costs are deduced from the benefits sum up to between 225,000 and 400,000 Euros. Additionally to the financial benefits enough equipment is available for all workers. Implementing these two strategies thus makes it possible to achieve the objective of the research to provide more equipment at less cost.

The introduction of the other six policies can be considered as supportive or complementary to the first two measures. Their costs and benefits cannot be determined with enough precision to be eligible for a quantifiable evaluation. The introductions of these policies do not lead to a calculated reduction of cost of the PEMS. They do seem to have an important impact on the success of using ILP and reducing the allocation factor. These measures do also improve other aspects of the work process and the costs benefit analysis of such adjustment should be executed in a research of which the scope extends that of this research.

Part V Conclusion

To conclude the research on the optimal acquisition and allocation of production equipment in this last part the main findings are recapitulated. A description of the new PEMS, the consequences it brings and the necessity of its implementation are described. This leads to a set of recommendations that should be implemented in a certain order of effectiveness to improve the PEMS. In some situations the research has lead to the formulation of new questions, which have arisen during the execution of the research. To finalize the conclusion a check is made if the formulated research questions have been answered to see if the research has been done to the client's satisfaction.

5.1 A new production equipment management structure

Having introduced adjustments to the PEMS it can be said that a new structure could be defined. In the new structure the AFD is provided a frequent update of the workforce planning from the production departments. Using the established equipment norms they can translate the workforce planning into a planning of equipment requirements. Based on this information, the equipment can be provided at lower cost if ILP and an allocation factor of 0.67 were used. In total a calculated saving of between 225,000 and 400,000 Euros could be realized on the planning of 2013 and 2014. The reduction of the PEMS costs can only be realized if simultaneously other management strategies are modified with the collaboration of the involved stakeholders. All the proposed changes in management strategies necessary to formulate a new PEMS are summed up in Part IV paragraph 4.2.1. The new management structure enables the AFD to provide sufficient equipment while saving expenses.

As the new PEMS might be implemented following all or some of the proposed strategies, its effectiveness becomes measurable. With data about the performance of the PEMS, the inputs and framework can be (re)evaluated. The performance of the management structure could point out shortcomings of the estimations made. Especially the determined norms of equipment needed per worker could be updated. Additionally the used prices for different acquisition methods can be determined with more precision once a database is set up with several acquisition agreements. The sensitivity of some inputs needed to use ILP modelling increases the complexity and accuracy of its implementation. Once using ILP, these sensitive parameters need to be identified and the user of the model should be made aware of the impact on the reliability of those parameters.

By implementing a cyclic process as illustrated in Figure 23 the changes will be updated continually and the model would become more reliable over time. The steps framed in red are those steps that have been described in this research whereas the other two steps need to be followed to enable further continual improvement. This continual improvement of the reliability of the PEMS should lead over time to a theoretical model that describes the reality with more and more precision.

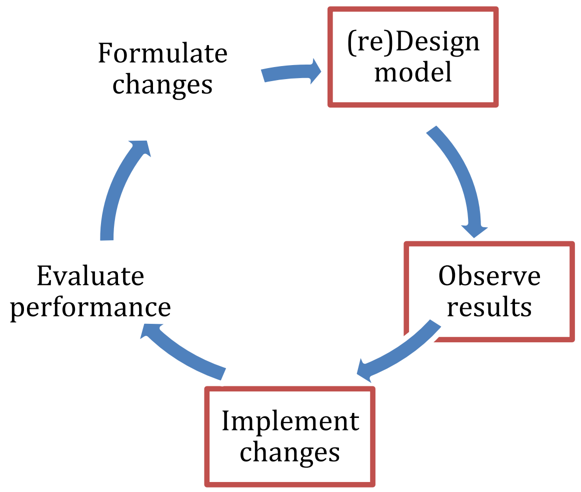

Figure 23 Cyclic improvement process

The two extra improvement steps introduced demand the collaboration of all the stakeholders involved in equipment management. The evaluation step aims to involve the stakeholders to bring up ideas of improvement. This strategy should increase the commitment of all parties, which is estimated to be an important element of success for implementation of the new PEMS. Especially the production workers who are initially not identified as important stakeholders become more relevant to involve once it is decided which changes to implement and they can help evaluate the structures' shortcomings.

The increased control on the equipment would enable more overall control on projects costs and the firm's profitability. The urgency of improving the control on equipment management might not be directly recognizable and it might be argued that the current management strategy suffices. To illustrate the urgency to improve equipment management, the following analogy (Slack et al., 2010)can be referred to from the book "Alice's Adventures through the looking Glass" by Lewis Carroll. In the book, Alice, the main character encounters living chess pieces, the "Red Queen" in particular.

> " Well in our country," said Alice, still painting a little, "you'd generally get to somewhere else- if you ran very fast for a long time, as we've been doing'."
>
> "A slow sort of country!" said the Queen. "Now here, you see it takes all the running you can do, to keep in the same place. If you want to get somewhere else, you must run at least twice as fast as that! "

This is used in the literature as an analogy to describe a business' environment and its competitors. It refers to the fact that in most cases simple innovations do not improve a firm's relative competitive position. To gain relative market position from their competitors firms must ameliorate their operational procedures more than their competitors. In the words of "the Queen" you must run twice as fast to get somewhere. Hence, it is important to improve the production process even if no direct failures can be identified in the current situation. Improving the PEMS should enable HFG to increase the efficiency of their work process in order to obtain a stronger market position.

5.2 Recommendations

To enable the realization of the previously described PEMS all adjustments, see Appendix V, might not be implemented at once. The order of implementation seems important as the performance will be evaluated before all changes have been made. Implementing the simpler and most effective changes first might convince the stakeholders during the implementation process to understand the usefulness of making changes to the PEMS. The modifications of the PEMS can in this way gain support during the implementation process starting from the first made improvements. Additionally, some changes cannot be implemented before some policies are adapted first.

The first recommended change to the PEMS is the reduction of the allocation factor of all equipment to 0.67. This is both the most effective and simplest adjustment to implement and it seems logical to start with this modification to improve the PEMS. Additionally, the evaluation of the effectiveness of this adaptation can be done quickly after its implementation. Once the implementation expenses are made the first benefit of having enough equipment should be rapidly observable. The implementation might encounter some opposition from the production workers in the beginning but on the long term they will realize what the benefits are once they are provided with sufficient and good quality equipment.

Following the reduction of the allocation factor, lean manufacturing should be implemented. As the realization of this management strategy has not been evaluated using a CBA the effectiveness of its implementation cannot be proven. Before, realizing this modification in the PEMS it is necessary to execute additional research to demonstrate the effectiveness of lean manufacturing. The implementation of this strategy needs to be done early in the process of changing PEMS. This change in management strategy will create more control on the available equipment. This extra control is necessary to administer the effectiveness of the modifications that are introduced later in the implementation process.

Once the allocation factor is reduced for all equipment, a new problem arises. The reduction of the allocation factor puts extra work pressure on the workers of the AFD and the administration system seems qualified for improvement. As proposed an *Internet of things* should be created to enable a decrease of costly human intervention in the administration procedures. Implementation cost of such an administration system seems justified if it leads to a reduction of labour cost and an increased control on the transactions of equipment. The detailed specifications of such an administration system should be made in collaboration with the production departments and the yard management. It would require specific information that is not analyzed within the scope of this research and the implementation of this management strategy requires additional research.

Having established more control over the available equipment and its allocation in this second phase of the implementation process, focus is put on improved acquisition methods. The use of internal cash flows might create transparency in the transfers of products and services between departments. This policy change aims to put the financial responsibility back at the user of a product/service. The user can then determine his need for equipment without consulting its necessity with colleagues from other departments. The proposed unit of measuring the transfers between departments is monetary as it can be linked easily into a department's budget. Other units of measurements could also be used and a throughout analysis into the best way to implement internal cash flows might be the topic of a new research. The implementation of internal cash flow is needed to be done before being able to implement ILP as this latter adjustment would otherwise not be able to function effectively.

As one of the main improvement proposed in this research, ILP is introduced at a rather late stage of the adjustment process of equipment management. The main reason for the late introduction of this adjustment is the complexity and lesser effectiveness of this management strategy. Due to the complexity the functioning of an ILP model, it should first be understood by its users. To obtain the necessary knowledge time is needed to train employees to operate the calculation model. Additionally, some changes have to be made to the PEMS and the equipments' environment before ILP can be used. Making predictions of equipment demand and using new acquisition methods for example need to be implemented before using ILP to optimize acquisition methods. Eventually the introduction of ILP can be done once the information and structure is adapted to its use. Besides reducing the allocation factor, using ILP is a calculated improvement to the expenses of the PEMS and it certainly is a modification that is recommended to be implemented.

Going through the necessary management strategies, some policies or management philosophies surfaced. Having effect on the way equipment is managed or used, in the last phase of the modification of the PEMS, these policies/philosophies need to be addressed to enable a successful implementation of the new PEMS. As stated in the description, the information used as input for the calculation model should be updated frequently and a cyclical improvement process should be designed. Changing the renewal policy of equipment and increasing the workers' responsibility aims to increase the motivation and the quality of the work environment of the workforce. It seems important to increase the accountability of the workforce and make them responsible for the way they handle equipment and make decisions. Granting more responsibility presumably increases the motivation of the workers which leads to more respect from their managers. The other way around, managers should consider their position toward the workers since the production workers will behave accordingly and stop to take considered actions if they are not fully-fledged. Enabling workers to take less important decisions will increase decisions' effectiveness and decrease the amount of time necessary from a manager to make low value decisions. Being provided with extra time the mangers can then focus on making more substantial high value decisions. Figure 24 summarizes the planning of the implementation process.

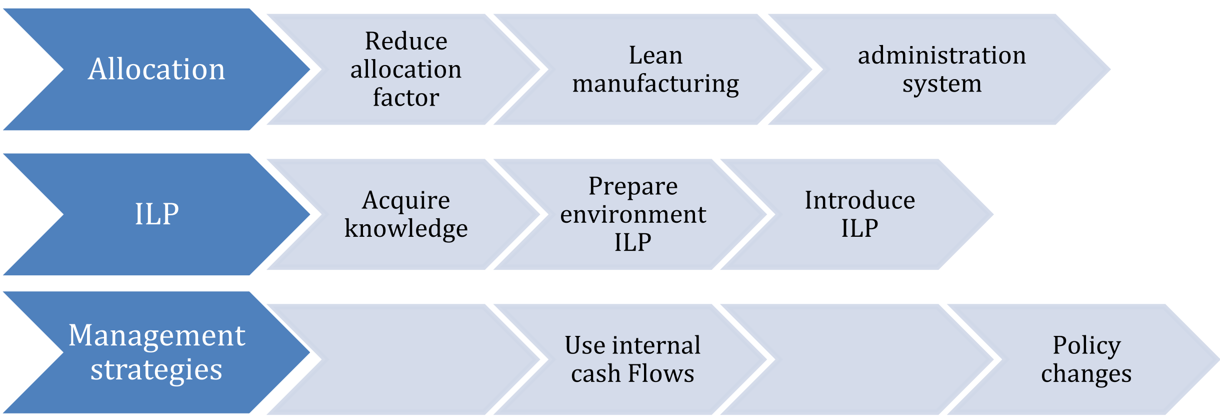

Figure 24 Implementation process

5.3 Research answers

As a check whether the research has appropriately answered the problems stated by the client, a control is executed on whether the research questions have all been answered. In this section the research questions are repeated and the corresponding answer is given or referred to as described in the research report.

What is the current management structure used to determine the quantity of equipment?

Based on the expected quantity of activities planned the production department makes a request for extra equipment no more than one month ahead. Based on this request and based on experience the AFD department makes decisions to acquire additional equipment and determines what the best acquisition methods are.

What is the available equipment?

The equipment studied in this research is described in appendix III paragraph 1 and the available quantity is provided in paragraph 2.1.4 of the main report.

How is the equipment used during the activities?

In the current PEMS most of the equipment is only provided to the employees at work, except for six types of equipment that are allocated to all the production workers employed by HFG. In section 2.1.1 a description is made of which of the equipment types this concern.

What acquiring methods are currently used?

Currently equipment is either procured or rented; financially the other acquisitions methods currently use by HG are not different from these acquisition methods.

What are the acquisition costs of the equipment?

An overview of the acquisition cost of the studied equipment is provided in appendix III paragraph 1.2 and in paragraph 2.1.2 of the main report.

What are the different types of activities executed at the Yard for which the studied equipment is used?

In the research five types of activities are distinguished: prefabrication, general/pipe fitting and general/pipe welding. In appendix II paragraph 2 a description is given of each of the activities and the required resources are detailed. In appendix III paragraph 2.2 an overview of the required equipment per activity is provided.

What acquisition methods would an ILP-model prescribe if it were integrated in the PEMS?

Once ILP has been introduced appendix IV provides an overview of how frequently a specific acquisition decision is made. This overview is a recapitulation of the tables that are the result of using ILP. The model specifies an acquisition decision for the quantity of equipment to acquire in a specific week.

How can an ILP-model link the activities with the available equipment?

The model calculates the gap between the required equipment demand, based on the workforce planning and the quantity of equipment necessary per activity, and the available equipment in stock. Then the model provides an indication how to provide the missing equipment optimally using ILP calculation techniques.

What does a new PEMS look like if it integrates an ILP-model?

This question is answered in the first section of the conclusion and the second paragraph of the realization part.

What costs does the new PEMS predict with the current activities?

The cost for providing additional equipment to the owned stock, using the new PEMS with the activities of 2013, are 50,000 Euros and 290,000 Euros with the planned activities of 2014.

What are the characteristics of the new PEMS?

The new PEMS uses ILP to make the optimal acquisition decisions and introduces three extra acquisition methods: lease, salepurchase, and resale. The new PEMS is also characterized by the fact that all equipment is allocated to only the workers at work and no longer to all the production workers.

What are the predictions for future equipment requirement using the new PEMS?

The predicted equipment requirements are obtained once the workforce planning is multiplied with the determined standard equipment required per activity/worker. Based on these predictions and the use of a new PEMS structure it is calculated that the predicted costs for providing additional equipment to the owned stock could be reduced with 225,000 Euros in 2013 and 400,000 in 2014.

What changes are necessary to implement the new PEMS?

To realize the new PEMS: internal cash flows, lean manufacturing, a new administration system and policy changes are recommended to be implemented.

Which improvements can a Production Equipment Management Structure (PEMS), integrated with optimization calculation techniques, bring to the determination of an optimal method of acquisition of equipment, required in an industrial environment, in order to reduce costs?

A new PEMS can better optimize the acquisition decision and calculate the consequences of improving the allocation of equipment. The use of such a management structure can lead to a reduction of 65-85% of the cost necessary to provide supplementary equipment. This equipment is additionally needed to the one already in stock in order to provide all the equipment requested by the production departments.

Abbreviations

AF	Asset & Facility
AFD	Asset & Facility Department
PEMS	Productions Equipment Management Structure.
HFG	Heerema Fabrication Group.
ILP	Integer Linear Programming.
OP	Optimization Problem.
AML	Algebraic Modelling Language.
AIMMS	Advanced Interactive Multidimensional Modelling System.
CPLEX	an optimization method using the simPLEX method implemented in the C programming language.
IoT	*Internet of Things*
MIG	Metal Inert Gas
TIG	Tungsten Inert Gas
PPE	Personal Protective Equipment
CBA	Cost Benefit Analysis
ROI	Return On Investment
NFC	Near Field communication
RFID	Radio Frequency Identification
EPC	Electric Product Code
NFC	Near Filed Communication

References

ANTONY, J., ESCAMILLA, J. L. & CAINE, P. 2003. Lean Sigma [production and supply chain management]. *Manufacturing Engineer,* 82**,** 40-42.
ATKINSON, R. 1999. Project management: cost, time and quality, two best guesses and a phenomenon, its time to accept other success criteria. *International journal of project management,* 17**,** 337-342.
BERTSIMAS, D. & TSITSIKLIS, J. 1998. Introduction to Linear Optimization. Springer.
BEUSINK, G. 2013. Interview Indutools.
BISSCHOP, J. & ENTRIKEN, R. 1993. *AIMMS: The modeling system*, Paragon Decision Technology.
BOURNE, L. & WEAVER, P. 2009. Mapping Stakeholders. *Stakeholder Management***,** 99.
BREALEY, R. A., MYERS, S. C. & ALLEN, F. 2006. *Corporate finance*, McGraw-Hill/Irwin Boston et al.
CHRISTOPHER, M. 2010. *Logistics and supply chain management*, Financial Times/Prentice Hall.
CPLEX, I. I. 2010. 12.2 User's Manual. IBM.
DANTZIG, G. B. 1998. *Linear programming and extensions*, Princeton university press.
DE BRUIJN, J., DE BRUIJN, H. & HEUVELHOF, E. F. 2008. *Management in networks: on multi-actor decision making*, Routledge.
ES-INTERNATIONAL. 2013. *Luchtgereedschap* [Online]. Available: http://www.es-international.nl.
FERRISS, T. 2011. *The 4-hour Work Week: Escape the 9-5, Live Anywhere and Join the New Rich*, Random House.
HACKMAN, J. R. & OLDHAM, G. R. 1976. Motivation through the design of work: Test of a theory. *Organizational behavior and human performance,* 16**,** 250-279.
HEEREMA. 2013. *Heerema Fabrication group* [Online]. Available: www.hfg.heerema.com/content/home/.
JOHN, N. 2003. *Project management for business and technology*, Prentice Hall.
KAMPEN, V. 2013. *lasdampafzuiger* [Online]. Available: http://www.vankampen.nl/.
KELLY, M. & ALAM, M. 2008. Management accounting and the stakeholder value model. *J Appl Manag Acc Res,* 6**,** 75-86.
KEMPPI. 2013. *las apparaten* [Online]. Available: www.kemppi.com.
KERZNER, H. R. 2013. *Project management: a systems approach to planning, scheduling, and controlling*, Wiley.
KORTE, R. D. 2013. Interview Europe Trade Nederland.
KUDVA, G., ELKAMEL, A., PEKNY, J. & REKLAITIS, G. 1994. Heuristic algorithm for scheduling batch and semi-continuous plants with production deadlines, intermediate storage limitations and equipment changeover costs. *Computers & chemical engineering,* 18**,** 859-875.
LASTECHNIEK, D. W. 2013. *Onderverdeling*

[Online]. Available: http://www.dewitlastechniek.nl/.
MANOWONG, E. & OGUNLANA, S. 2009. Strategies and tactics for managing construction stakeholders. *Construction Stakeholder Management***,** 121-137.
MAXTOOLBOX 2013. Toolboxes.
MCCALL, J. J. 1965. Maintenance policies for stochastically failing equipment: a survey. *Management science,* 11**,** 493-524.
MENDELOW, A. Stakeholder mapping: the power/interest matrix. Proceedings of the 2nd International Conference on Information Systems, December, 1981. 7-9.
MURRAY-WEBSTER, R. & SIMON, P. 2006. Making sense of stakeholder mapping. *PM World Today,* 8**,** 1-5.
NAHMIAS, S. & CHENG, Y. 1997. Production and operations analysis.
PFEFFER, J. 1998. The human equation. *Boston, MA*.
PLUIJMERS, B. 2013. Interview Heerema Fabrication Group.

SLACK, N., CHAMBERS, S. & JOHNSTON, R. 2010. *Operations management*, Pearson Education.
SOYOUWANNA. 2013. *Cutting equipment* [Online]. Available: http://www.soyouwanna.com.
STEIGLITZ, K. & PAPADIMITRIOU, C. H. 1982. Combinatorial optimization: Algorithms and complexity. *Prentice Hall, New Jersey., UV Vazirani (1984). On two geometric problems related to the travelling salesman problem. J. Algorithms,* 5**,** 231-246.
TOOLSXL. 2013. *Sliftslijpers* [Online]. Available: http://www.toolsxl.nl.
VELTION. 2013. *Schaduwbord* [Online]. Available: www.veltion.be.
VERSCHUREN, P. J. M. & DOOREWAARD, H. 2007. *Het ontwerpen van een onderzoek*, Lemma.
VETH. 2011. *Lean manufacturing* [Online]. Available: www.veth.net.
VITESSE. 2013. *Vorkheftruck* [Online]. Available: http://www.vitessevorkheftrucks.nl.
WOLFE, P. 1959. The simplex method for quadratic programming. *Econometrica: Journal of the Econometric Society***,** 382-398.

Appendix I Workforce planning

To be able to make a forecast of the equipment demand the workforce planning, provided by the structural and piping department, is used. In this Appendix the used planning of the prepers, fitters and welders is given for the planning periods of 2013 and 2014.

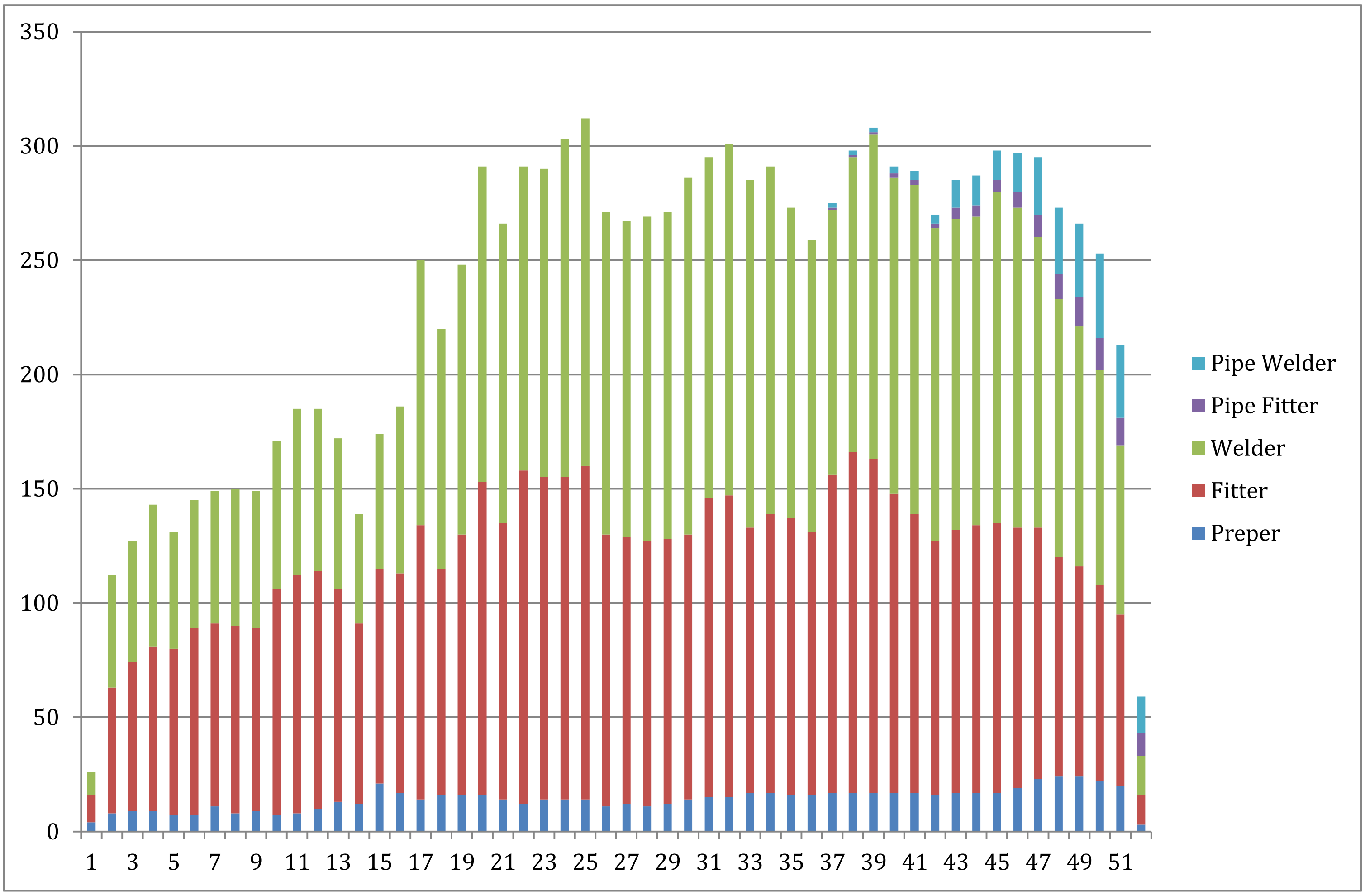

Figure 25 Workforce planning 2013

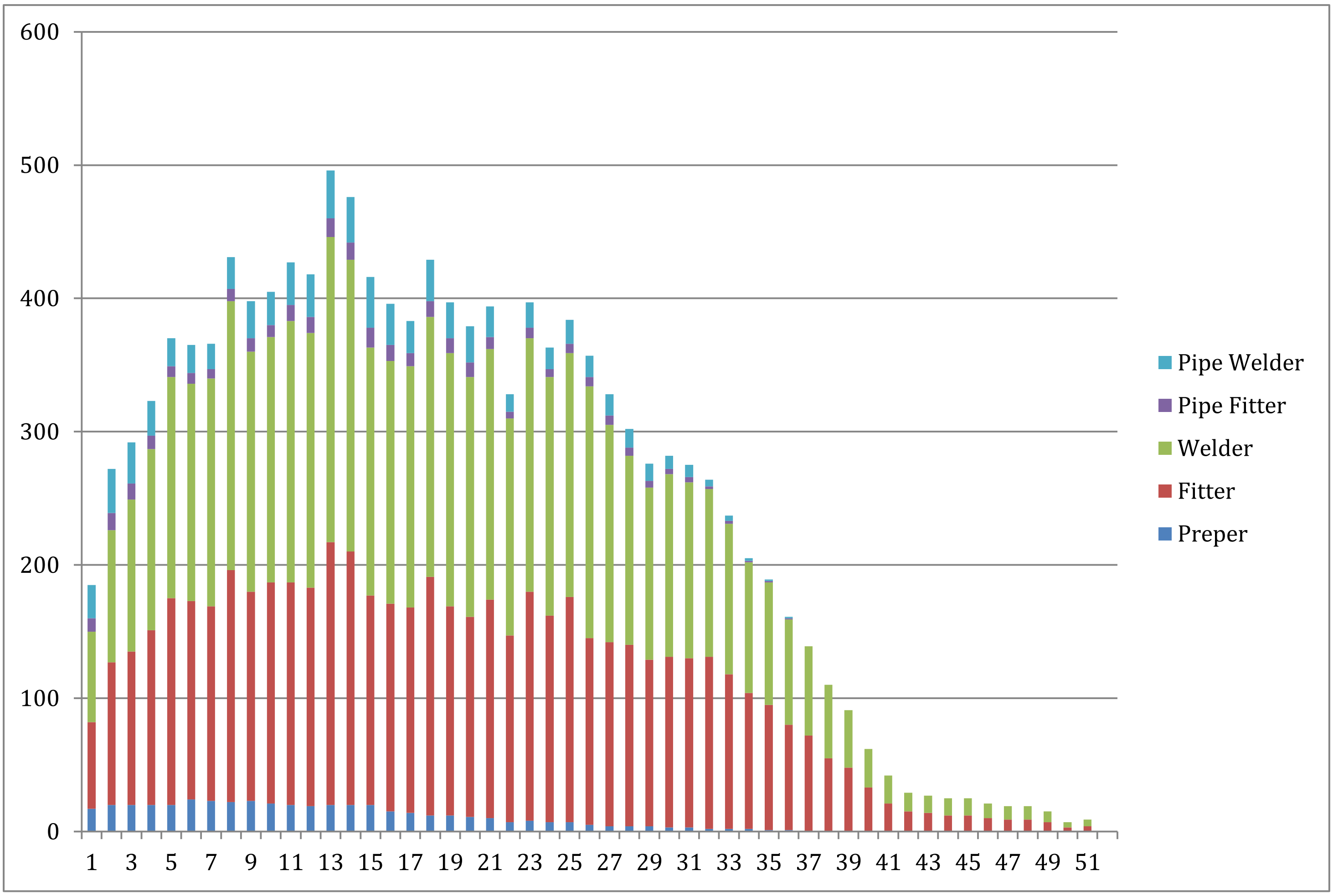

Figure 26 Workforce planning 2014

Appendix II the PEMS environment

A.2.1 Equipment

Starting from a list of more than 15.000 different pieces of equipment in the database the quantity of studied equipment is reduced to a relevant list of 1500 pieces of equipment. This means that a large number of equipment was either used for only one type of activity or it was too insignificant to be monitored and did not fit in the scope of the research. The studied 1500 pieces of equipment can be divided into 18 different types of equipment. These 18 equipment types are being described in this paragraph by giving 7 different descriptions as some type of equipment are quite similar. Once having formulated the description for each equipment type an idea is formulated of the possibilities and constraints that these equipment types have.

A.2.1.1 Disc cutters

One of the most used pieces of equipment are disc cutters and they can be divided into three different types of subcategories: normal air powered, turbo air powered and electric powered. Disc cutters are used to cut and sand steel in order to prepare and position the steel such that a weld can be made. A disc cutter can also be used for finishing after the weld is made.

The most common cutters are the normal compressed air driven disc cutters. They are safe and the cheapest; these cutters are being replaced with turbo cutters that are newer and more powerful, which makes them more comfortable to work with. Both air powered cutters are connected to a high pressure air tube to be powered.

The high frequency cutters are electricity powered and used less since they are not very safe in use because of the possibility of electrocution. The high frequency enables the number of rotations to be bigger which make them easier to cut with. The power cord that is needed for a high frequency cutter is thinner and electric cutters are easier to handle than air powered disc cutter.

Sub-category	Displacement	Resource	Illustration
Normal	Easily	Compressed air	 **Figure 27 Disc cutter(es-international, 2013)**
Turbo cutter	Easily	Compressed air	
High frequency cutter	Easily	Electricity	

Table 15 Overview disc cutters

A.2.1.2 Pin tolls

Once the crude work is done with the disc cutters on preparing the metal for the weld, pin tolls are used. The pin tolls can remove swarfs if still present on the metal structure. During the weld it is also used to remove eventual splashes. Pin tolls are mostly air power pieces of equipment and therefore need to be connected to the air supply network. In most aspects pin tolls have similar constraints as disc cutters. As with disc cutters there also exist a high frequency variant of pin tolls. These are electric powered and are more comfortable to use since the equipment is able to make more rotations than the air powered variant.

Sub-category	Displacement	Resource	Illustration
Normal	Easily	Compressed air	 Figure 28 Pin toll (toolsxl, 2013)
High frequency toll	Easily	Electricity	

Table 16 Overview pin tolls

A.2.1.3 Forklift truck

These machines enable the displacement of small pre-assembled components, large pieces of metal and equipment that cannot be lifted manually. Forklift trucks need specific maintenance knowledge that at this point is not available at HFG Zwijndrecht yard, therefore the maintenance is outsourced. The trucks can be moved around the yard quite easily and are powered with fuel. Most of the forklift trucks are used for large variety of activities and a lot of which are not within the scope of this research. Forklift trucks are acquired for general use and besides the demand based on the scheduled manpower more trucks are used to perform transportations.

Figure 29 Forklift truck (Vitesse, 2013)

A.2.1.4 Welding equipment

This equipment description regroups different types of equipment that are all directly related to welding. Depending on the chosen welding process a different machine can be used. Heerema Zwijndrecht uses different welding processes: TIG and MIG. For each welding process different machines can be used depending on the duration, material dimensions, and the type material on which the weld needs to be done. The welding machines are big and are usually put on a chariot on which supportive equipment such as the welding wire is also mounted. A tack machine is a smaller welding machine that can be used for short welds to keep the prepared materials in place awaiting the real weld. Due to the shorter duration of the welds heat does not develop much and therefore the cooling system is smaller, a tack machine can be seen as a small welding machine that can be carried by one man. In the category of welding machines gouging machines can also be placed, this is as a very large welding machine that can develop a lot of heat, and melt the metal again. The gouging machine is used to remove low quality welds in order to correct mistakes.

All welding equipment use electricity and gas to operate and cannot be moved around easily in the production halls except for the tack machines. Since different resources are needed to make the equipment work the machines are connected to a complex network of cords, tubes and distribution units. A relocation of one machine requires a rearrangement of this resource supply network. The machines are quite heavy which makes transportation complicated. A last piece of equipment is put in this category of equipment and this is the weld vapour extractor. This machine absorbs the fumes from the welding process and keeps the welding environment safe. If this machine is big it does however only need electricity to work and it can be relocated more easily than the welding machines.

Sub-category	Displacement	Resource	Illustration
MIG	Hardly	Electricity, Natural/Mixed gas	 Figure 30 Welding machine (kemppi, 2013)
TIG	Hardly	Electricity, Natural/Mixed gas	
Tack	Easily	Electricity, Natural/Mixed gas	
Gouging machine	Hardly	Electricity, Natural/Mixed gas	
Welding vapour extractor	Average	Electricity	 Figure 31 Welding vapour extractor (kampen, 2013)

Table 17 Overview welding equipment

A.2.1.5 Cutting equipment

Being provided with large plates of metal, workers need to cut the metal to desired dimensions and for that they use big cutting machines but also portable beetle cutters and hand cutters. Most of the cuts are done in the prefabrication hall but if during assembling cuts turned out to be incorrect the workers need to cut them in the construction. Once already in the construction only beetle and hand cutters can be used to perform the cut. The cuts are done with machines that use a flame to cut through the materials. For straight cuts a chart is used to guide the cut along a line; these are the portable beetle cutters. The chart follows rails that have to be maintained into position to guarantee a clear straight cut. In case a circular cut or other non-straight cut is required most of the time a hand device is used. For both cutting procedures the machine requires gasses. These machines are most of the time used in the prefabrication hall a large number where connection points are available at the wall. In case of cutting in the assembled structure the resources need to be supplied through a network of tubes tube and distribution units.

Sub-category	Displacement	Resource	Illustration
Portable Beetle cutter	Easily	Compressed air and natural gas	 Figure 32 Portable beetle cutter (soyouwanna, 2013)
Hand cutter	Easily	Compressed air and natural gas	 Figure 33 Hand cutter (soyouwanna, 2013)

Table 18 Overview cutting equipment

A.2.1.6 Toolboxes

Each production worker at HFG is provided with a toolbox filled with a standard set of tools. The toolbox also provides a possibility for the workers to lock up their equipment during their time off. These types of equipment do not have any further constraints and can be displaced easily. The tools inside a toolbox dependent on the activity of each production worker; there are two types of toolboxes one for fitters and one for welders. From the two types of toolboxes the fitters' toolbox is the simplest one, as no special welding gear a welder requires, needs to be put into this toolbox. The workers work in couples and usually a set of tools is brought to the work place where the workers tend to exchange the tools. After some time the tools become unequally distributed as some equipment is not given back once borrowed from a co-worker.

Figure 34 Toolbox (maxtoolbox, 2013)

A.2.1.7 Distribution units

Most of the required resources for operating equipment are provided through a network of cables, pipes and distribution units rallied to connection points attached on the wall. As the platforms take form these networks need to modified and extended, as the equipment can no longer be connected directly with the points on the wall. Besides serving as extension cords this equipment makes it possible to temporary provide gas/electricity on the work locations. This category of equipment figures as important link in providing equipment the necessary resources. In a situation were insufficient distributions units are available activities can be restrained. The distribution units also create the possibility to connect several devices on one extension cord/tube to reduce the amount of cables/tubes. Tubes are connected to transport the gas under pressure to the desired location. The distribution units of gas all look similar for each gas however the compressed air version also includes a storage tank to guarantee the pressure in the tubes. Once disconnected these are pieces of equipment that can be relocate easily. The compressed air distribution unit is a little heavier and cannot be relocated by one person.

The electricity distribution units connect the electric cables needed for all the equipment. These distribution units exist in three versions; the biggest version has the confusing name of mobile distribution unit. On this device the largest pieces of equipment and smaller distribution units can be connected. A mobile distribution unit is very heavy and a large number of cords are connected to it, this makes it equipment difficult to relocate and it is the least mobile of the three eclectic types of distribution units. The smaller units can be used if a smaller amount of electricity is used and less equipment needs to be connected to the distribution point. The smallest distributions unit of the electricity type are those that are only used to provide power for light.

Sub-category	Displacement	Resource	Illustration
Distribution unit mixed gas	Easily	Mixed gas	 Figure 35 Distribution unit gas (lastechniek, 2013)
Distribution unit natural gas	Easily	Natural gas	
Distribution unit compressed air	Average	Compressed air	
Mobile distribution unit light	Easily	Electricity	 Figure 36 Distribution unit light (lastechniek, 2013)
Distribution unit	Average	Electricity	 Figure 37 Distribution unit
Mobile distribution units	Hardly	Electricity	 Figure 38 Mobile distribution unit

Table 19 Overview distribution units

A.2.2 Activities

In this research only equipment is analysed that is used in specific activities performed by production workers. To understand the functioning of the equipment a description is made of the activities in which they are used.

A.2.2.1 Prepers

Arriving in the prefabrication hall as steel tubes or plates the materials need to be cut and prepared to the correct dimensions. The workers performing these activities are responsible to cut out elements to the dimensions according to the given drawings. Not only do they prepare the elements on the dimensions, the workers in the prefabrication hall or prepers do also cut the edges of the elements such that the weld can easily be applied. In a situation where it is very busy sometimes the steel elements are already pre-assembled to form small components. Some intersections of the construction are very complexes and require a large amount of welding. The duration of the construction can take up to several months and is usually done by prefabrication workers since the work environment is more comfortable than in the larger assembly halls. The prepers collaborate closely with the fitters and try to distribute the work evenly to make the work process as fluent as possible.

The equipment that each preper needs is one disc cutter with which he can carve the edges of an element with or clean up a surface that needs to be welded. Each team of two prepers is said to need one pin toll one cutting torch and one portable beetle cutter. Besides the large cutting machines that can cut the steel mechanically this equipment is needed to make less conventional cuts and prepare the sub component to be easily used by the fitters. If the prepers cannot do their work correctly the components they deliver to the fitters is not of best quality and the fitter needs to spend more time to fulfil his task correctly. In the prefabrication hall all the resources are available closely and attached to the walls. Estimated is that on average one forklift truck is needed in the prefabrication hall to rapidly move the elements through this part of the production area. For each preper the fitter type of standardized toolbox is the one that fits best the needs of a preper.

A.2.2.2 Fitter

As the preper has done his work the fitter is responsible to put the element or sub-component in their final position. With the help of drawings everything is assembled to form larger components, sub sections and eventually a section is made and put together. At each step the fitter assembles the components and attach them using a temporarily tack weld. The fitter needs to check if the construction fits the tolerances and they look if the actual construction fits the made design by doing measurements. Before each step in which bigger components are assembled the welders need to perform their work and in case the fitter does no perform his work correctly the welders needs to correct his deficiencies. A practical example of such deficiency is the situation in which two elements are apart with an unnecessary large gap. This means that the welder has to overcome more space with his weld, which will mean that it will take him longer to accomplish the weld.

The fitter usually works around or within a section or subsection and he needs to displace his equipment constantly. At the same time he needs to readjust the resource supply such that his equipment keeps working. All these relocations need to be done in the safest way imaginable and therefore a fitter does not spend all his time in fitting elements and preparing edges for a welder. The fitter does also build temporary constructions that are needed to move a sub section or keep the elements in place in order to make the connection between two components. The construction of such temporary constructions usually needs to be done with the same precision since the failure of the construction would mean a delay in the lift or weld.

The fitters are said to be using two disc cutters; one 5” and one 7” this avoids constantly having to change the discs which formally has to be done at the storage room. Providing two disc cutters to the fitters seem more efficient than letting them constantly walk back and forth to the storage room. The fitters do also use a pin toll to remove swarfs or splashes from the components. It is important for a fitter to use the best quality disc cutter or pin tolls as he spend a lot of time using this equipment. In a situation where a fitter has to use a disc cutter above his head for several hours a turbo variant of the disc cutter will mean significant reduction in work time and increase the work comfort. A turbo disc cutter rotates faster and makes the cuts easier which means the fitters has to spend less time in an uncomfortable position. Once the elements are positioned and prepared for the welder, the fitter uses his tack welding machine and makes temporary welds to hold the elements in place. Each pair of fitters is also equipped with one cutting torch in case that a cut needs to be made through thicker material or is of a shape impossible to realize with a disc cutter or pin toll.

The workspace of each production worker needs to well lighten and each light mobile distribution unit provides enough power for 5 workers. One unit should be available for every five fitters in case that the area where the work is performed is too far away removed from the fixed connections on the walls. The same goes for the provision of the gasses on which each distribution unit have 10 plugs to branch the equipment on. For each 10 workers 1 distribution unit of each type of gas must be foreseen. For the electric mobile distribution units and normal electric distribution unit one of each type needs to be foreseen for respectively every 8 and 5 workers. A group of fitters also need one forklift truck in each hall in which no more than a hundred fitters work at once. A fitter is equipped with his own standardized toolbox in which he can find tools to perform the measurements and other general tools.

A.2.2.3 Piping fitter

Comparable to the general fitter the piping fitter works in a different environment. Assembling pieces of tubes that will transport the harvested resources on the platform is for the biggest part done in the pipe shop. This is a different part of the production plant and focuses only on cutting tubes on the right dimension and making curves and intersections for the pipes. The harvested resources are usually transported under high pressure and therefore the connections between elements have to been of an even higher quality than those welds made on the structural part of the platform. The piping uses significantly less equipment due to the fact that they are working in especially equipped work areas where all resources are available to make the equipment work. All equipment can directly be plugged into the wall and therefore no distribution units are used to relocate resources in the pipe shop. The idea is that in the pipe shop the elements are displaced and not the equipment. In total a piping fitter uses one high frequency disc cutter and one high frequency pin toll and he has a fitters' toolbox that is adapted a little for use in the pipe shop. The reason that he can use high frequency equipment is that it can directly be plugged into the wall without the need for a hazardous network of electric cables. Like all other halls one forklift truck is needed to move heavier components around and eventually bring them to the assembling halls where the pipes are fitted into the construction.

A.2.2.4 Welder

The welder performs the final activity necessary to realize a connection between elements. The duration of his work depends on the quality of work the prepers and the fitters have delivered. At the end that he has applied his weld it is checked by the quality control department and if approved the work on the connection is done. The welder assembles elements that form at each step bigger components. In the assembling hall the production workers cooperate to produce bigger components to eventually form sub-sections. These sub-sections are the largest size of elements that can be displaced with a crane and from that point on displacement can only be done using special trailers that are provided by a sub contractor. The sub-sections are assembled to form a section, an element of which the size is limited to the size of the painting and sanding halls. Once the sections are painted they are assembled together to form the platform. Within the platform a lot of work is still to be done on assembling the sections and for example installing staircases.

Each welder uses two disc cutters and one pin toll to be able to correctly do his work or finalize the tasks of the fitter. Similarly to the fitter the welder needs the same amount of distribution units in order to posses over the resources to make his equipment work. Welders are each also equipped with a MIG welding machine; MIG is refers to Metal Inert Gas welding which is a specific welding process.

In the welding process an electrode is fed through a welding gun and the electrode melts due to the electric current that flows through it. A gas also flows through the gun to protect the melting process from containments in the air. In order to cause the electrode to melt high amperage needs to be developed. As this amperage is constantly built up within the welding machine it heats the machine and the more amperage it develops the more heat it produces. This heat can damage the machine and the machines need to be cooled using water system that is electrically powered. The welding machine also holds a wire box containing a large roll of the electrode that is fed through the welding gun. The whole is gathered on a cha rt to enable the welder to transport it easily horizontally.

The welder works in an environment were a lot of fumes and heat is developed. He wears protective clothes and a mask that protect his eyes from the sparks that are produce by the melting of the electrode. Making a weld is a continual activity that can some time take several days depending on the size of the weld. During such a monotonous process some mistakes are made and in order to make corrections a gouging machine is needed for approximately every 8 welders. A gouging machine needs to develop more amperage than a MIG machine and is even bigger and less manoeuvrable. In case that the weld is done in a confined space a welding vapour extractor is set up to vacuum away the bad fumes. On average one welding vapour extractor needs to be foreseen for every 4 workers. The welders all need a specialized toolbox that contains the special welder masks and PPEs necessary to assure the workers' safety. To move around the equipment and materials in each hall one forklift truck should be made available for a team of welders.

A.2.2.5 Piping welder

Similar to the fitters there exist specialized piping welders that do the same activities as general welders but in a different environment, additionally they also need a TIG welding machine. This extra welding equipment is needed because they make different welds due to the materials they use and the thickness of the pipes.

A TIG machine is similar to the MIG machine but differs from one point that the electrode is not fed through the welding gun but is fed manually between the material to weld and the welding gun, which provides only the high amperage current and the protective gas.

As with pipe fitters the pipe welders do not need to assemble a network of wires to get the resource on the work spot but they can use the nearby connections on the wall. The piping welder uses for the same reason as the pipe fitter one high frequency disc cutter and a high frequency pin toll. Besides the TIG machine he needs a MIG machine and a special welder box. To be fully equipped a forklift truck is needed in the pipe shop ready to be used by a welder. Working with high frequency equipment has a disadvantage since the machines are electrically powered they are more vulnerable to theft as anyone could use them at home. To be able to use a stolen disc cutter that works on compressed air fewer people have the disposal over an air compressor that makes it less interesting to steal.

A.2.3 Stakeholders

A.2.3.1 Asset & Facility

Responsible for the equipment of the company the AFD takes care of safeguarding the condition of the equipment and performs most of the general repairs. At this moment it is their responsibility to provide sufficient equipment to all the workers at the yard within a given budget. The introduction of a new PEMS could enable them to reduce their expenses and might increase the control they have over the equipment. It is imaginable that the AFD is supportive to the introduction of a new PEMS. The AFD would be able to provide knowledge to increase the control they have on the equipment. In the current situation only the manager of the AFD possesses the knowledge necessary to forecast the equipment demand. In a new structure other employees of the department should be able to make a forecast as well. It is in the departments' interest to transfer the knowledge from the manager and incorporate it in a new structure where it is accessible for everyone on the production yard. In this way the knowledge necessary for equipment management is more embedded in a structure than in a person. Besides having the responsibility on the management of equipment the department does also ensures the relation with the sub-contractors who hire equipment to the company. The AFD has the financial resources to make decision about the quantity of equipment available which gives them a very powerful position regarding the PEMS, the department does however have to justify the made cost towards the yard management. With the help of their high influence they have a great incentive to make changes to the PEMS, as the demand that the production provides them is too high for the budget with which they are provided. The AFD needs to make changes to the manner in which they manage the equipment as they are challenged to provide more equipment for fewer resources by the yard management.

A.2.3.2 Logistics &Materials

On the yard a lot of objects needs to be displaced between the moment that they arrive at the yard until the moment where they are used and assembled in the platform; the logistics & materials department is responsible for these displacements. It is their responsibility to make sure that the materials needed are in the correct place at the correct time. In a situation where equipment is poorly managed or not available in enough quantity the department has more work to do, as equipment has constantly to be displaced to another urgent user. If enough equipment is available the transport and material department will have more space to decide when to transport equipment as it suits them best. Their involvement with equipment management is limited since equipment does not fall under the departments' responsibilities. This explains their limited power, neutral position and weak need for changing the structure in which equipment is managed. It might not make them the most important stakeholder when considering changes to the equipment management but still they could provide useful information. Their experience on working with other departments can be acknowledged when reorganizing equipment management

A.2.3.3 Procurement

This department is responsible to analyze all aspects of how to acquire the needed resources for the projects at the best value. The value of procurement is related to the notice in which it needs to be made available, the more the acquisition procedure is started ahead the better value can be negotiated for the object.

This procedure is followed in practice when it concerns materials such as steel or larger components but in theory all procurements made by the AFD need to be revised by the procurement department. In reality this is only done when it requires larger financial resources. The freedom in which the AFD can purchase products correlates with the quality of the relation with the procurement department. If such a link is not good the acquirement procedures can become lengthy in time and procedures will complicate the activities of the AFD. The procurement department has no direct power on how the equipment is managed, but in a complex company as HFG adding up the figures is an important evaluation method of someone's work. Making the best value acquisition decision is something in which the procurement department can be very helpful and it would enable to be evaluated positively. This makes the procurement department opinion about management decisions quite influential, valuable and to be considered. As cost specialists they have a better view on the lowest price of resources and thus their knowledge is valuable to increase budgets efficiency. With their experience on different acquisition methods the equipment management could be improved and their ideas can be incorporated in a new PEMS.

The department might be a little reluctant to collaborate on making adjustment to the PEMS as this might increase the amount of work they have to perform. From their perspective there is no direct need to change PEMS since they have not much to do with the manner in which it functions at the moment. Their performance will not be improved if equipment is management more efficiently and at less cost.

A.2.3.4 Yard management

The yard management concerns all those activities that are not exclusively project specific, which creates a huge overlap with the responsibilities of the project department. Projects are defined(John, 2003) to have a limited duration and do normally not incorporate long term strategies of the firm. If such long-term strategies were not made the company would risk losing its market position in the long run and encounter financial uncertainty at the end of a project. Orienting themselves towards future requirements the yard enables the company to always provide the clients their needs and incorporate long-term strategies. It is from the yard management that policy changes are usually originated. By keeping a good link with the yard management the AFD is made aware of future changes and can anticipate on them. Together with the yard management the budget for equipment is determined and the management should be strongly supportive to provide more equipment at lesser costs. With support from this hierarchical superior placed department the proposed changes can be imposed with the use of their power position and financial capacities. The high influence of the yard management can only be utilized once the strong need is demonstrated and it is proven that such changes would enable a gain of control on equipment. The gain of control should eventually lead to a situation where the management has a better insight in cost certainty and be able to make better estimates.

A.2.3.5 Production

Consisting of several sub-departments production organizes the workers, make sure that deadlines are met and that the quality of work is guaranteed. Working under commission of the project managers they are the users of the production equipment and its management needs to be fine-tuned with them. They have the knowledge about the activities that they are performing and are useful sources of information. If they provide planning information consistently equipment could be prepared preventively. At this moment the relation with the AFD is not the best as production have an incentive to exaggerate their equipment requirement. Building in a margin in the communicated quantity of required equipment the AFD considers it necessary to interpret the given information cagey. The quality of information is distrusted and in some situations management of equipment is failing and creates planning issues.

To observe the malfunctioning of relation with the AFD we can take the example of a situation in which the production manager requires an X amount of equipment in week Y. The manager of the AFD only provides a part of this equipment quantity X as he thinks that this quantity of equipment should be sufficient. From the AFD managers' perspective the production manager over estimates his requirements and thinks the communicated demand equals the maximum quantity needed over the total duration of a project instead of the quantity only needed in week Y. During the project the required quantity of equipment fluctuates and especially at the beginning and the end of the project the production manager needs only a part of the quantity requested. The production manager does not need a quantity X of equipment during the total duration of the project.

In addition to this complex relation the production department is also divided in a structural and a piping part that both need to be approached differently. If production performs most of the work it is however the responsibility of the project department to make sure that projects are completed in time, budget and meet the quality requirements. The production department is provided with a fixed budget for which it should be able perform the activities which it got assigned. The production department has the objective to minimize the costs necessary to perform these activities for which it is responsible. Availability of more and better equipment would improve the efficiency of the work process. Making adjustments to the equipment management structure would contribute to the goals of the production department. The production department seems to be supportive to idea of making modifications to the way equipment is managed. Their influence can be used to enforce the implementation of the changes.

A.2.3.6 Production piping / structural

Within the responsibility of the production department two distinct divisions are formulate that each might have a quite different position towards changes of the way equipment is managed at the moment. It is under these divisions' supervision that the production workers are managed and it can be expected that they are not in favour of changes and preferably do like to continue to work the way they do now. If they do not have much power and not much influence the production workers are nonetheless the end users of the equipment. From their position of end-user the production worker does contribute to a large extend to the success of the changes made to the PEMS. With the idea of being provided with sufficient equipment in the future the structural and piping divisions might be inclined to collaborate and provide their experience on the use of the equipment. Making them increase a little bit the efficiency and realization time of the construction they might turn out to be helpful and willing to review their position about changing the management of equipment. The activity that these two departments execute is the construction of all the steel parts of an energy platforms construction. The structural division assembles all the pillars, beams, steel floors and ceilings. Once the staircase and strips for internal walls are installed sub-contractors that are managed by the project managers carry on the work. The piping division makes sure that all pipes that transport the harvested resource are installed on the platform. The pipes arrive as tubes and need to me manipulated and the flanges need to be attached to them in the piping and prefabrication halls.

A.2.3.7 Project managers

A large part of the core-activities is executed by the production department, which means that activities of the project managers are intertwined with those of the production department. Once the production workers are done the project manager has to find contractors to perform the work in which HFG is not specialized. These contractors are usually long-term relations and the work environment is similar as the one in a department where the company employs all workers. The project department does have a separate relation with the AFD to provide the contractors with necessary equipment. This means that the project department is responsible to coordinate sub-contractors and their supply of resources. Performing long duration projects the department works with a large number of contractors on a continual basis. These sub-contractors are present at the yard for a long duration and they bring their own equipment, the AFD is usually only asked to provide equipment in an emergency. In some situations it is contractually determined that HFG provides certain types of equipment. The project department tends to have a good relation with the AFD since most equipment requests are ad-hoc, as the equipment requirement cannot be predicted; and they are put on the projects budget. Most of the services or equipment that the project managers require can directly be booked on the projects budget and the project managers provide for extra financial space to acquire the equipment. The main concern of the project managers is to assure that the platform is completed on time and he would be willing to address any inefficiency in the work process. The project managers' medium influence, medium power and neutral position on how the equipment is managed does not make the project manager a stakeholder off great assistance in implementing policy changes concerning equipment management. Their weak need of influencing equipment management is due to the fact they have no interest in the manner in which it is done as long as equipment is provided appropriately.

A.2.4 Equipment management strategies

As it has been acknowledged which stakeholders form the environment of the equipment management, a description can be given on how some aspects of equipment management are approached.

A.2.4.1 Budget

To cover the expenses made by the AFD a budget is provided based on the number of man-hours planned for a project. The estimated budget of the AFD is built up with 6.5 Euros (Pluijmers, 2013) for every planned man-hour on the project. It is the departments' task to provide enough equipment while keeping the expenses within this budget. The budget is not provided by the production management who uses the equipment but by the yard management. The production management does not borrow internally the equipment and they can require as much equipment as they would like. In the case production is requiring large amounts of equipment the AFD will not be granted more budget. The overall management will confront the AFD if they have not respected the budget in case that too much equipment was provided. This creates a situation where the user and the sponsor of the equipment are not always aware of the gap between the foreseen and required equipment. The equipment demand and budget are not dynamically linked.

A.2.4.2 Procurement

The equipment within HFG is acquired in two different manners. If the company buys the equipment the procurement has to go through the procurement department that will try to negotiate the price of the product. This department has an overview of the competitive price of the products and the status of the relation with the supplier. If however the equipment is hired it can be done internally at the AFD that then has responsibility of making sure it negotiates the best price. The decision to make the procurement of a new type of equipment or renting it is based on experiences of using the products in the past and the estimated use in the future. These arguments for acquisition are however not based on registered facts that could be found back in a database. This lack of information makes it difficult to reveal the operational costs of equipment and make valid considerations. More experienced and usually key persons in the organization are those that have this information and experience and the acquisition decisions are usually based on their recommendations.

In case of an increased requirement of equipment the decision is taken to buy or hire more equipment as needed. This makes the current acquisition strategy ad-hoc and most procurement decisions cannot be considered over a longer period. In the current PEMS most equipment is always available when needed with the exceptions were the supplier is unable to deliver the equipment in time. This is sometimes due to an increased demand from competitors or fabrication problems of equipment in the manufacturing plant. If a new PEMS would be designed the level of availability should be aimed to be better or similar to the current degree of availability.

A.2.4.3 Predictions

In order to make balanced decisions about the correct moment of acquisition a prediction is needed of the future equipment requirements. In the current situation a rough estimation is made based on the observation of the quantity of work being executed at the moment. Additionally the production department provides a heads up in case of a swift increase of activity or the need of special equipment. These predictions are usually not made further than one month ahead and at most requests for extra equipment very little time is available to make sustained acquisition decisions. If the AFD would have an insight on activity predictions for a longer period it would be able to make better cost benefit analysis's to make procurement or rent decisions. Besides being able to negotiate better prices knowing the equipment demand further ahead can be advantageous for another reason. In case the equipment requirement is know in advance the supplier can be alerted and he can be asked to ensure to have the equipment available in due time. Knowing the equipment requirements more in advance has thus different advantages and it seems interesting to find a structure in which a prediction of the equipment requirement is made for the coming year.

A.2.4.4 Administration

Once equipment is acquired it is entered into Plannexpert, a software package that makes it possible for management to have an overview of the certifications and calibrations of the equipment. The system inventories all equipment types and keeps track of the repairs that need to be done in order to get the machines operational again. The software is also able to determine the age of the equipment and determine if the condition of the equipment justifies replacement.

Internally the maintenance can be done on electric equipment and failures can be helped out which avoids the department having to hire a specialized supplier to do the repairs. This strategy is only interesting in the case that enough machines are owned to keep the mechanics busy. For some types of equipment the repairs are too specific and exceptional that out sourcing the repairs is more interesting. The certification and education of the employees could turn out inefficient if the knowledge is not substantially used. With the administration of the equipment it can be determined how much work needs to be done in order to keep the equipment operational.

The administration system cannot keep track of what someone does with the equipment once he has borrowed it. In case equipment is missing it cannot be found back and determining who holds responsibility for the equipment is complicated. The equipment could either be left on the platform that went off shore, it might be stolen or it might be lost out of view while tidying up the work area. If theft is an issue losing it out of view might be even more problematic. The equipment might surface after a long period and workers will start using it again. In that case the certification might not be up to date and workers will be working with unsafe equipment. In case of an inspection this can be translated to considerable penalties. The equipment that is not certified might no longer function properly and cause dangerous work conditions.

A.2.45 Setting off equipment

In the current PEMS, equipment is provided to workers and the equipment is registered to their name. This enables the equipment manager to trace who he can address if he needs to get the piece of equipment back. With this way of distribution most of the equipment is always somewhere in the production hall. The equipment is only returned in case of repairs and at the end of a project. With this administration strategy of the equipment the AFD does not have a lot of control on where the equipment is. Having assigned a piece of equipment to a certain worker does not mean that he actually possesses that piece of equipment. In most cases the equipment is borrowed out to colleagues and the equipment is untraceable again.

Due to incorrect handling of the equipment some production workers prefer to keep the best equipment for themselves and lock it in their toolbox overnight. During another shift workers are not able to access this equipment and an extra set of equipment is required for the teams working in that shift. This might create a situation were plenty of equipment is available however it stays locked in the toolboxes of those who are not at work. This creates a very inefficient work situation and if a worker has a broken piece of equipment or it need replacements he does in the current situation not have to justify how the equipment ended in this condition. Production workers that are continually not taking care of their equipment cannot be identified and approached to adjust their behaviour. In the current equipment management strategy there is no procedure in setting off equipment that would motive the worker to handle equipment with more care.

The combination of the fact that no one is directly accountable and that everybody tries to keep the best equipment for themselves creates a situation in which equipment is not well taken care of. As it is not always clear what the exact number of workers is at a given moment, equipment can be left unused in the production halls as there is no incentive to return it. The observation of the equipment management and its environment made it possible to identify some failures and an indication can be given of what solutions might look like.

Appendix III Inputs

A.3.1 Costs

To compare different acquisition methods more realistic information about the procurement, operational and rental costs is needed. Obtaining a unique and reliable price to use for the calculations seems difficult due to the fact that the relation between the supplier and the company has a big influence on the determination of the price. The price also differs between suppliers and the accuracy of the information can be questioned. Other aspects about cost information are depreciation and the determination of operational costs they are described as well in this appendix.

A.3.1.1 Pricing

Based on the information obtained from ET Nederland(Korte, 2013) we can summarize the pricing procedure as follows. First the manufacturer determines the resale price at which he wants to sell the products based end-users willingness to pay. Depending on the length of the supply chain and the demand of the product, the manufacturer will approach wholesalers to which he can sell the product. The wholesaler and the manufacturer together agree on a discount on the final resale price. The discount is determined depending on the quality of the collaboration and the quantity that the wholesaler wants to acquire. The wholesaler then repeats this process by selling to smaller wholesalers or directly to shops or customers. At each step a stakeholder of the supply chain will scoop off a small portion of the discount the manufacturer provided at the first transaction. This process works for a large number of products but especially for professional products it can be relevant to know. Making bigger quantity orders or renting for a longer period might enable the company to negotiate substantial discounts. The decisions of acquisition can, in the current situation, only be made based on a prediction of the equipment requirements in the short future. This limits the negotiating options of the AFD.

Being informed about the way in which the price of equipment is determined we can examine that the price dependents on whom we ask the price from. All different stakeholders of the supply chain do however operate with one unique price, which is the gross price of the product that equals the resale price to the end-user. Since this research focuses on the comparison between different management strategies the most important aspect of the pricing is that they are provided from the same starting point to enable a fair comparison. It seems justified that using the gross price during this research enables a good starting point to make price comparisons. The gross price is also currently used to make a cost benefit analysis to sustain the procurement decision. As it is already used at the moment it can be considered to be reliable information to evaluate adjustments of the PEMS on.

A.3.1.2 Accuracy

Having determined which price will be handled during the analysis another accuracy issue has become distinguishable. The needed quality of equipment is known at the AFD however the suppliers do not all provide the same quality. This is due to the fact that supplier are highly specialized in a specific part of the market. If a supplier fails to provide a certain level of quality this is mostly due to the fact that most of the suppliers' clients do not require very high quality equipment. The products are usually still used as temporary solution in wait for arrival of higher quality equipment. The provided quality of equipment has an influence on the renting and procurement price of the equipment. It does not seem reasonable if the used prices in the research are based only on one source, as this would give reasons to doubt the accuracy of the research. This is resolved by making an average price calculation based on the prices provided by several suppliers to obtain reliable information.

The firms that provided information about the equipment prices are:

- Euro Trade Nederland; which is a company specialized in selling all types of professional equipment and has decided to extend their activities by providing rental services. (Korte, 2013)
- INDU-Tools; A supplier of mainly rental services on a large scalar of industrial products. (Beusink, 2013)
- HFG; The user of the equipment
- Several other suppliers (LasPartners, Euroweld, Atlas-Copco Nederland and A&N Europe) from which prices are obtained from catalogues available internally at HFG Zwijndrecht.

The table below summarizes the procurement and rental prizes obtained during the research aiming to increase the accuracy of the used costs for the calculations.

	Rent				Procurement			
	HFG	ET NL	Indutools	Average	HFG	ET NL	Indutools	Average
Disc cutter*	60	60	22	47	900	1306	195	800
Pin toll*	45	59	25	43	700	989	240	643
Mig welding machine	150	135	165	150	6000	6100	7500	6533
Tig welding machine	175	115	180	157	4500	4370	7000	5290
Tack welding machine*	65	90	100	85	2000	2250	2500	2250
Gouging machine	153	120	145	139	6500	3600	4500	4867
Welding vapour extractor	125	150	140	138	1200	1650	1800	1550
Cutting torch*	30	18	20	23	200	129	260	196
Beetle portable gas cutter	85	285	85	152	2500	4845	1450	2932
Distribution unit light	30	36	25	30	1200	739	250	730
Distribution unit mixed gas	48	48	75	57	1000	1295	700	998
Distribution unit Natural gas	48	48	75	57	1000	1295	700	998
Distribution unit compressed air	48	48	37	44	1000	1295	400	898
Mobile distribution unit	310	36	85	144	15000	739	1200	5646
Distribution units	125	48	130	101	1500	986	1300	1262
Forklift truck	200	0	0	200	60000	0	0	60000
Welder Toolbox*	60	35	18	38	600	1544	210	785
Fitter toolbox*	60	35	22	39	600	1544	400	848

Table 20 Price accuracy

A.3.1.3 Depreciation

Equipment as with any other asset will lose its value over time. Depreciation is taken into account for the total value of the firm's assets for two reasons.

First the costs made to purchase an asset, or in this specific case, equipment needs to be allocated to a specific activity or period in time. The reason to take into consideration this aspect of depreciation is that firms will be able to spread expenses for larger assets over several years. If the accounting were not done in this way this would mean that a firm could make big losses in a year that large number of assets is purchased. To avoid making losses the firm would be inclined to constantly postpone these purchases.

A second aspect of depreciation is the loss of value of the product. The equipment will have to compete with new similar products that have better efficiency. At the moment that equipment is purchased the market will continue to improve and develop new products. After some time it becomes interesting to analyse if it is better to keep the product or resell it and buy a new one that is more efficient. Once equipment is purchased and used it will also show user traces that affect the product's value. Concerning the equipment at Heerema Zwijndrecht production yard most of the equipment is not depreciated since it is written off within the same year.

The smallest equipment types that are depreciated over several years are the gantry cranes in the production halls. This points out that the equipment within the scope of the research is too insignificant for detailed accountability from a perspective of the HFG Zwijndrecht yard. This means that all equipment that fits in the scope of the research is purchased and is considered to have no rest value at the end of the year. In the years following the purchase the equipment has no costs but operational ones. This strategy has for consequence that the profitability of a project cannot be determined with great accuracy. If most purchases are done in the years that project 1 is executed the following project will seem more profitable as some costs are already accounted for in the first project.

A.3.1.4 Operational costs

Once a product is used it brings some costs with it, these operational costs are mainly consumables that need to be replaced to ensure optimal use of the equipment. After a longer period of use the probability of failure of the equipment increases gradually. Once the equipment fails it need to be repaired at costs that depend on the type of failure and the equipment type. In this research the operational costs are limited to the costs related to maintenance and repair. The costs made to replace consumables are not taken into consideration since these costs are the same independently of the way in which equipment is acquired.

The maintenance costs, or from this point on operational costs, are determined using a ratio between maintenance and procurement costs. This ratio is the same as the ratio that the AFD uses when making CBAs. This maintenance/procurement ratio is 1, 2.5 or 5% of the gross resale price. Which ratio to use depends on the type of maintenance frequency the concerned type equipment needs. Having determined the yearly maintenance costs we can compute this to weekly operational costs. To not simply provide the same maintenance costs every week and take into account the increase of the failure probability rate as the equipment becomes older the maintenance cost are multiplied with an ageing factor. The ageing factor enables the use of operational costs that take into account an increasing failure rate probability following an exponential failure distribution. This distribution describes the phenomenon that the probability of failure increases over time. After a given time this ageing factor will equal 1 describing a situation of equipment that needs normal maintenance. In the beginning there will be less maintenance needed and the factor will multiply the maintenance cost by a value between 0 and 1. Further description of how the operational costs are build up will be given in the framework paragraph 2.1 of the main report.

A.3.2 Demand

To implement a management strategy applicable for different production department's information should be used that all those departments use. The decision to use this information is made to increase the applicability of the results of the research. To determine the equipment demand we can use the planning of the workforce of each production department as source of information. The planning is at the moment also used to communicate the needed estimated workforce between the production departments and the human resources department. The production departments translate the design of the topside into activities that need to be executed by production workers. Based upon the experience they have on the number of workers needed to perform these activities they can make the construction planning. In this research the demand of equipment is based upon this workforce planning. The workforce planning is based on an estimation of activities and is updated as the work is progressing. In order to keep the equipment planning in line with progressed work a frequent update of the workforce planning should be given from the production departments. The planning used in the first run of the model can be found in appendix I and consist of the planning of the workforce in 2013. Once this planning has been used to estimate the equipment demand of 2013 it is compared with the actual used equipment in this year.

A.3.2.1 Precision and flexibility

The labour planning is provided in weeks and the planned equipment requirements will also be determined in weeks. It seems reasonable to maintain this time unit for the planning in this model. A larger time unit would only decrease the precision and quality of the research and equipment demand predictions. In the opposite direction a shorter time unit is not realistic either since this would require a more detailed planning of activities and labour. There is however a disadvantage by linking the equipment to the planned workforce. Labour is relatively static in comparison with equipment as it requires longer procedures and higher cost to increase or decrease its supply especially on the short term. Equipment does not have this constraints and it could be managed more dynamically. It seems reasonable for example to expect the possibility to increase the quantity equipment within several hours. Such a swift change cannot be expected for workforces where more workforce needs to be planned at least one week in advance. By linking the equipment to the workforce the opportunity to manage equipment more dynamically than workforce is taken away. In a situation where the equipment demand is studied from a different perspective and apart from workforce it might be possible to increase the dynamics of the equipment management system. To perform such a different management approach more knowledge and information should be gained of the performed activities in order to directly recognize a certain need of equipment corresponding to a planned activity or production process.

A.3.2.2 Equipment norm

Being provided with the planning of prepers, fitters, and welders needed to complete the project, a prediction can be made about the equipment needed to complete the planned activities. To be able to make a prediction of the required equipment per type of worker a norm of equipment requirement must be established. To gain insight in the quantity of equipment needed for each worker research is done by interviewing team leaders and foremen and ask them to give an estimation of the equipment quantity they deem necessary for their men. Provided quantity of equipment needed per worker, this norm can be multiplied with the number of workers planned and a planning about the equipment demand is obtained. The accuracy of the equipment planning is based on the reliability of the workforce planning and the established norms of equipment needed per worker. The reliability of the workforce planning can only be taken for granted, while interviewing more managers or making more observations can increase the accuracy of the requirement norms. Table 21 shows the norms considered to make precise predictions of future equipment demand.

The exact number of equipment needed for each worker can hardly be determined as it is a matter of personal interpretations if one needs one piece of equipment per two workers or one each. One team leader estimates that the availability of a large amount of equipment increases the efficiency of his team while another team leader might argue that this is not true. With the calculation of the estimated requirement it can be checked if the predicted equipment requirements do coincide with the reel demand of the equipment in that period. In case the predicted demand turns out not to match the required number of equipment the norms of equipment required per worker should be adjusted to make better predictions. Such a modification should lead to an increase over time of the accuracy of the predictions.

	Preper	Fitter	P-Fitter	Welder	P-Welder
Disc cutter*	1	2	1	2	1
Pin toll*	0.5	1	1	1	1
MIG welding machine	0	0	0	1	1
TIG welding machine	0	0	1	0	1
Tack welding machine*	0	1	0	0	0
Gouging machine	0	0	0	0.15	0
Welding vapour extractor	0	0	0	0.25	0
Cutting torch*	0.5	0.5	0	0	0
Beetle portable gas cutter	0.5	0	0	0	0
Distribution unit light	0	0.2	0	0.1	0
Distribution unit mixed gas	0	0.1	0	0.1	0
Distribution unit Natural gas	0	0.1	0	0.1	0
Distribution unit compressed air	0	0.1	0	0.1	0
Mobile distribution unit	0	0.15	0	0.1	0
Distribution units	0	0.2	0	0.2	0
Forklift truck	0.01	0.01	0.01	0.01	0.01
Welder Toolbox*	0	0	0	1	1
Fitter toolbox*	1	1	1	0	0

Table 21 Equipment norms

A.3.2.3 Planning scope of workers

The planning provided as input concerns only the planning of people that are directly managed by the firm's own employees. Computing this information into equipment requirement will only predict the requirement of equipment for these employees. For some activities sub-contractors are found to perform work that is not part of the company's core-activities. These sub-contractors sometimes need to be provided with equipment. This demand of equipment is hard to determine in advance since the collaboration with a sub-contractor can be set up on a short basis. The flexibility in allocating extra workforce with the use of sub-contractors increases the uncertainty about the equipment demand. The value of this flexibility in workforce is bigger than the value of having more control over the equipment demand. Working with sub-contractors is a fact that cannot be changed if we want to stabilize the predictions of equipment demand. The activities performed by the sub-contractors are not taken into account and the equipment demand of only the workers managed by the firms employees are taken into considered in the optimization of the PEMS. The output of a new PEMS only gives an insight of how to acquire the equipment needed for the own personnel and additionally some equipment should be reserved for the use of sub-contractors. The exact number of equipment needed should be determined with the help of an interpretation of the models' output and the observed past requirement to provide sufficient equipment for all workers. Limited input quality of data translates itself into poor quality of the new information that the model creates. The end-user has to take into account the lack of accuracy of the input data in order to still be able use the results of the predictions.

Having researched and analysed the data about the cost of acquisition and the demand requirements of equipment, sufficient data is gathered to start determining how to integrate this into a calculation model to determine the costs. In the part II the procedures explain how the used input data is computed into the framework that can be used in the calculation model.

Appendix IV Values of X

As a result of using ILP to calculate the optimal acquisition methods the model provides a value Z that represent the total cost needed to suffice the forecasted equipment demand. This value Z is the sum of the calculated values of X that are multiplied with the corresponding cost of each acquisition decision. In this Appendix an idea is given how much and when a certain acquisition decision is taken when applying modifications to the model. In a way this gives an idea what the values of X are in each of the runs of the model.

- Run 1 corresponds to the calculation of the model where only purchase and rent can be used as acquisition methods.
- Run2 corresponds to a situation where all studied acquisition methods are used.
- Run3 corresponds to the calculation of the optimal acquisition methods when applying an allocation factor of 67% to all equipment.
- Run4 corresponds to the calculation of the optimal acquisition methods when applying an allocation factor of 33% to all equipment.

In the table the quantity of unused equipment is also provided to determine the efficiency of the quantity of equipment in ownership once using a specific calculation strategy.

2013

	2013run1	2013run2	2013run3	2013run4
Unused equipment	249	249	336	880
Rent	1257	787	132	7
Purchase	369	26	3	0
Lease	0	26	2	0
SalePurchase	0	372	92	6
Resale	0	26	3	0

Table 22 Quantity acquisition decisions and unused equipment 2013

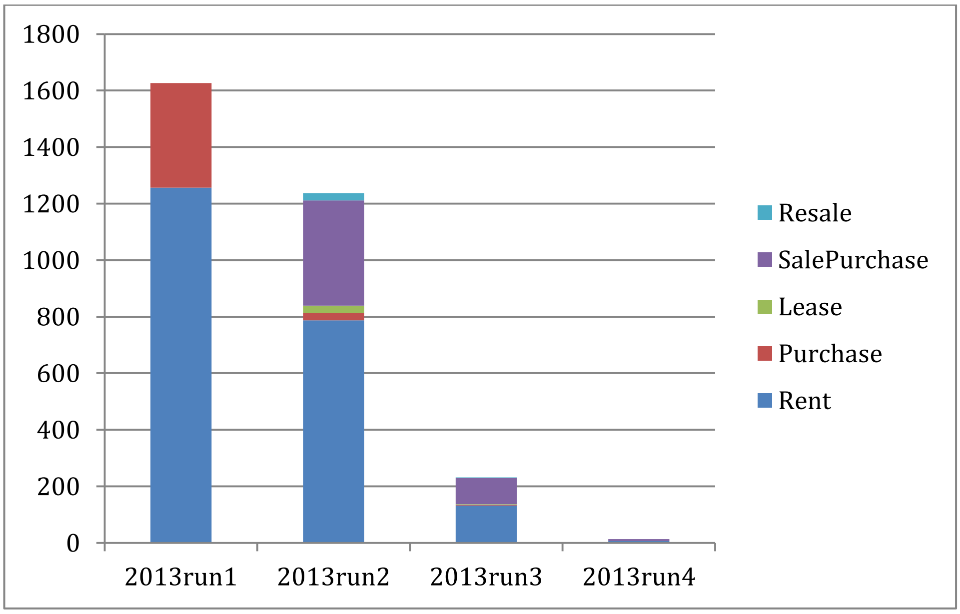

Figure 39 Acquisition decisions total 2013

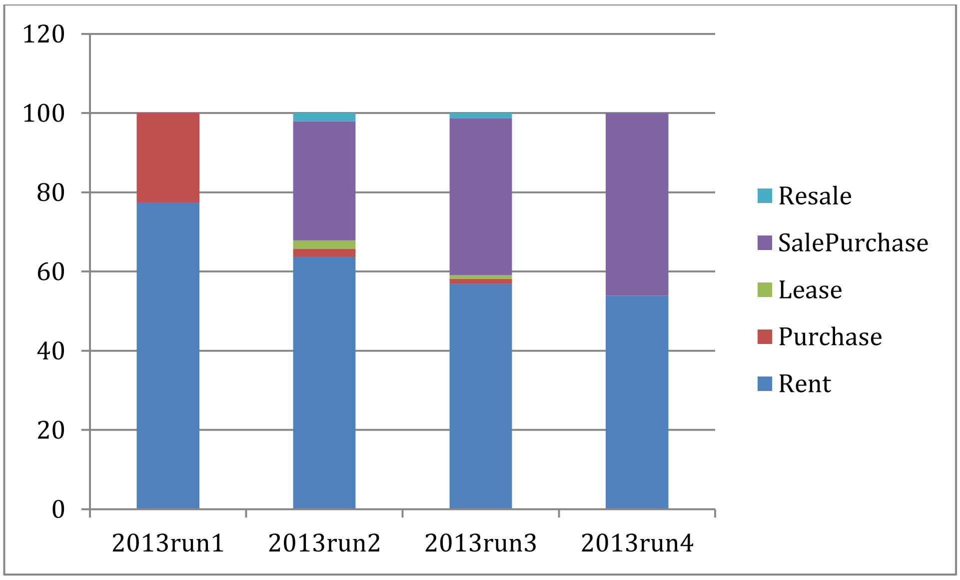

Figure 40 Acquisition decisions relative 2013

2014

	2014run1	2014run2	2014run3	2014run4
Unused equipment	126	126	165	598
Rent	4378	1973	1213	118
Purchase	659	0	0	0
Lease	0	62	26	1
SalePurchase	0	738	287	13
Resale	0	0	0	0

Table 23 Quantity acquisition decisions and unused equipment 2014

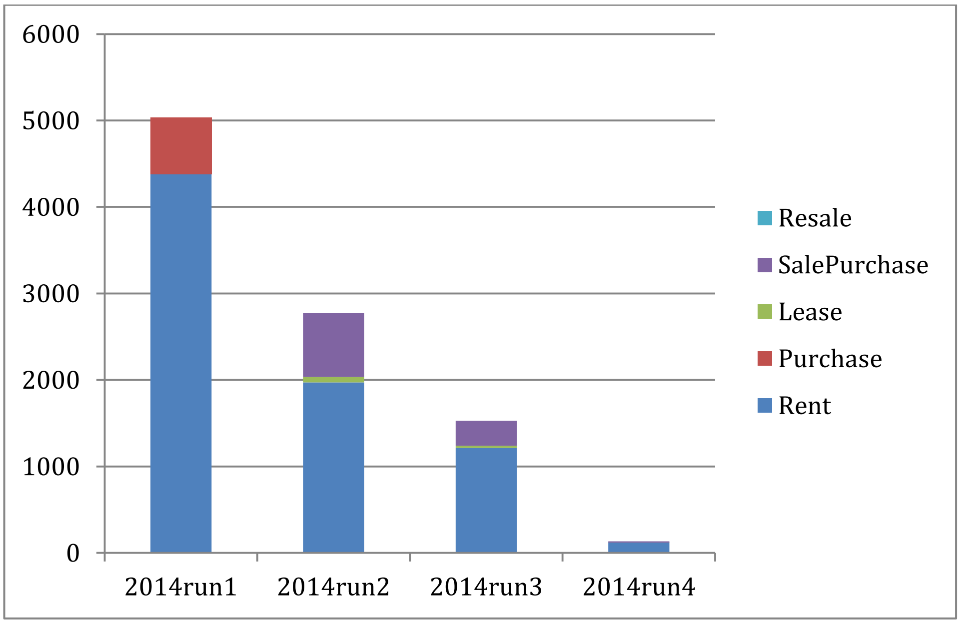

Figure 41 Acquisition decisions total 2014

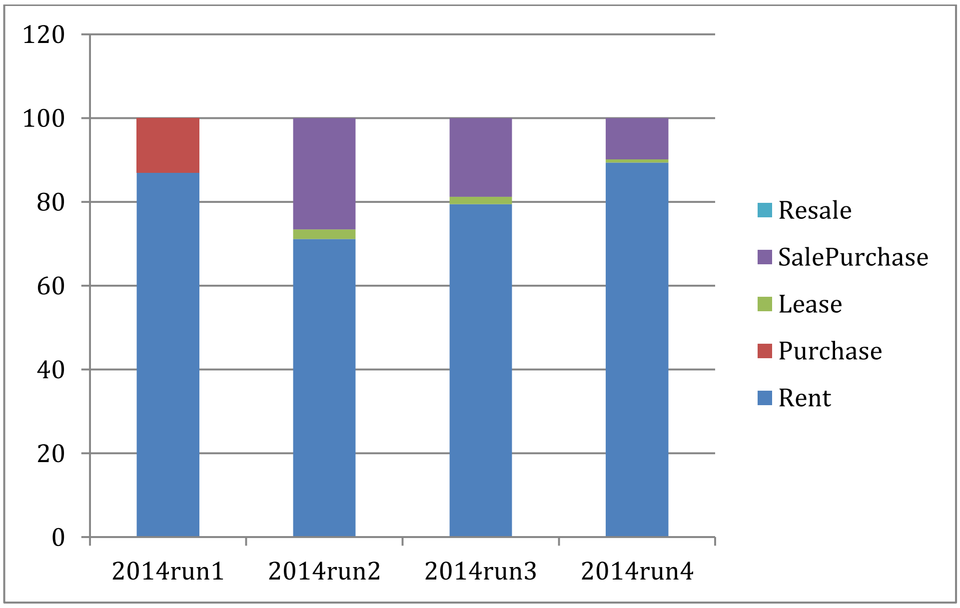

Figure 42 Acquisition decisions relative 2014

Appendix V Implementation strategies

A.5.1 Using ILP

The programming of a new calculation method for acquiring production equipment requires some adaptations in the current management structure to be fully integrated. A model makes predictions of equipment demand and determines the moment at which a specific acquisition decision needs to be made. To obtain precise information about the moment of acquisition and be able to fully profit, the benefits of using ILP the calculation procedure should be used properly. Training someone to obtain the knowledge would require time, and the functioning of the model needs to be fully understood to avoid misinterpretations. In the current PEMS the equipment is requested only at the moment that it is needed but the integration of ILP creates the possibility to know the equipment demand at forehand. To be able to make good predictions it is important to have reliable information. Reliable information can only be obtained in case the departments collaborate in a transparent manner. This change in attitude of transparency between divisions is an important part of the success of integrating ILP into the PEMS.

The use of the ILP will change the provision of equipment from a corrective procedure towards a preventive one in which the acquisition is done before a shortage will take place. The modifications will consist of an investment of time in the beginning of the implementation, on the long term it will replace time-costly strategies on corrective provision of equipment. It is estimated that during half a year one day a week should be needed to understand and use ILP as a tool for equipment management. After this period the time needed to operate ILP calculation should become equal or lower to the time needed for provision of equipment in a corrective strategy.

Besides a change in procedures within the company and between the departments the agreements with the suppliers have to be reviewed. To enable reselling equipment and integrate it as an acquisition method it first needs to be checked with a supplier if he could find a market for second hand products. The same holds for a Salepurchase acquisition method for which a supplier needs to be found to realize this acquisition method. These types of modifications have to be implemented by the procurement department that also seems the department needed to perform the tasks of reselling equipment. Focus on reselling is not only important to obtain a better optimum in acquisition methods but it also puts emphasis on getting rid of unused objects. This has not directly an impact on reducing costs but it is part of a standpoint in which unused objects are not accepted.

To be able to properly evaluate the benefits of implementing ILP, the costs necessary to make the adjustments are also taken into account. It is estimated that an office employee has to work one full day a week for six month or an investment of 26*1*(60,000/(52*5)) = 6,000 Euros needs to be made. The time to operate ILP will after a half year no longer be considered as an extra investment as at that point the exchange of information between department is considered to go more fluently. To let the software execute the necessary calculation a licence for AIMMS has to be procured which based on the manufacturers price list would mean an investment of 13,000. Reselling of objects in general will generate some revenue and it is therefore not considered to be a management policy that requires extra costs to be implemented. In total implementing ILP should justify a total investment of 19,000 euro to become financially interesting.

A.5.2 Internal cash flow

Within the divisions at the HFG yard Zwijndrecht services and products are exchanged between departments without having a trace of how and how many of these exchanges take place. Budgets are provided to each department unrelated to the number of services they have to provide. When a project is obtained each department is budgeted a percentage of the tender price based on an estimation of the expenses made for that project. This strategy enables the management to directly evaluate the effectiveness of a department and see if each of them respects the budget that is forecasted. So it happens that the department responsible for a service/product is not the same department as the one that uses it. Since between the departments there is no budget exchange this might create disagreements. A user will prefer the convenience of full availability of the service/product while the owner will prefer less availability to save costs. This situation occurs when for example unused equipment is not returned to the storage room while the AFD is still paying rent for that equipment and has no idea that it is unused.

To manage equipment more dynamically the user of the service or product should have an incentive to stop/return it as soon as he does not need it anymore. The best imaginable motivation is money and by creating a cash flow between the departments the user will return the product/stop the service once it is no longer needed. It provides the department who is supplying the services or products with a cash inflow that is equal the quantity of services or products delivered. The departments become more competitive as each will try to increase effectiveness to maintain their budget and use as little amount of services/products as possible. Figure 43 illustrates the change of exchanges made between departments once internal cash flow is introduced.

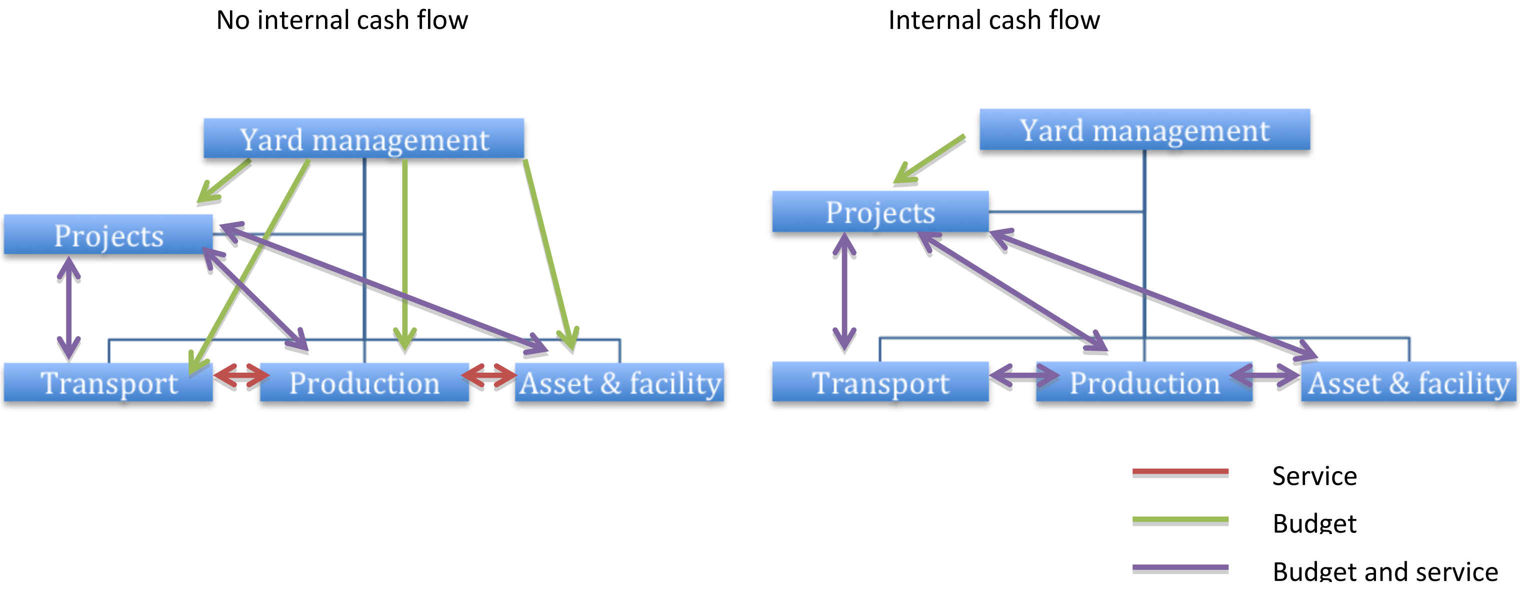

Figure 43 Exchanges between departments

With the introduction of internal cash flows the dynamics of a new PEMS are ensured, as departments responsible for the equipment have a better overview of what is used and what not. It is no longer a problem if a production team decides to keep equipment, as they will make payments to the AFD for as long as it is not returned. Installing a cash flow does also provide the manager with an overview of what they are using on equipment and they can consider which items to return to reduce their weekly internal bill. The AFD can on the basis of the predicted equipment demand make more balanced decision on how they want to acquire equipment. The acquisition decisions could be made undependably from the equipment requirement if forecasted equipment demand is precise enough.

The change in management strategy will generate a larger number of invoices and extra work for the managers of the departments. It is estimated that in total one employee would be busy administering the cash flows one day a week for each department. This concerns the bigger departments of the yard and in practice the workload will be divided over several employees in the department. The resources necessary to implement this new management strategy do affect several processes in the organization and creating internal cash flow would not only be beneficial for equipment management. The administration system should to be redesigned or adopted to facilitate the use of internal cash flows. Establishing internal cash flows will facilitate the work of management since the expenses are monitored closely and financial overviews can be generated quickly. The creation of internal cash flows is a management policy that has extensive implications that beyond the scope of this research. The costs of implementing internal cash flows cannot be estimated only on the increased needed manpower and new administration system. The implementation of internal cash flows is therefore considered as a recommendation without a detailed cost benefit analysis. If there is an interest in implementing internal cash flows, further research is required to perform a proper analysis. It is considered that the introduction of internal cash flows is beneficial for the quality of the PEMS.

A.5.3 Allocation Adaptations

Performing calculations has brought to light that besides introducing ILP into equipment management reducing the allocation factor has a big influence on the cost of the PEMS. In the current situation there are six types of equipment that are allocated for a full 100% to each worker. This means that at any moment there is always a large quantity of equipment unused. In order to realize the reduction of unused equipment two implementation strategies exist. Each strategy corresponds to a category in which the six types of equipment can be subdivided. The first category assembles the mechanical equipment that has moving parts. Disc cutters, pin tolls and tack machines are the types of equipment that form this category of equipment. The other three types: toolboxes and cutting torches form the category of tools. For both the categories the allocation has to be reduced to 67% in order to realize cost reduction. A different approach for each category is chosen to realize such economies.

A.5.3.1 Mechanical equipment

This category of equipment is one that is very valuable for the effectiveness and work comfort of the workers. In the past it has been decided that every worker should be provided with his own piece of equipment and take responsibility over the condition in which it is. Besides the correct use the worker is also responsible to replace components that are consumed while the equipment is in use. These parts are called consumables and need to be replaced frequently. The mechanical equipment does also need to be certified yearly which consists of a check of the correct functioning of the tool. For safety reasons the consumables have to be replaced at maximum every 8 hours and in some situations more frequently. This means that even if the equipment falls under the responsibility of the worker theoretically the tool has to return several times in the week to the AFD.

To reduce the allocation factor for these equipment types it seems realistic to no longer provide each worker with his own piece of equipment but to stock the equipment at the AFD. The equipment has to be picked up at the beginning of the shift at the AFD and at the end of the shift all equipment needs to be returned. This means that the employees of the AFD can at the end of the shift replace all consumable parts and give the equipment a quick check. At the beginning of the next shift the equipment is inspected and the consumable parts are replaced. This will avoid that during his shift the worker has to return to the AFD to replace the consumables of the equipment. For the employees of the storage room this would mean an increase of activity at the end and beginning of each shift to provide every worker with equipment as fast as possible and to replace all the consumable parts.

The cost of implementing this strategy is build up by only the increase of activity of the employees in the AFD. For the production workers submitting their equipment at the end of their shift and picking it up at the beginning of it does only replace an action that they have to perform anyway when they are replacing their consumables. The resources required to implement this strategy depends on the way the implementation is done. If the same administration is used one piece of equipment can be handled approximately every 20 seconds by one worker which means that if all equipment is handled at once this would take a half an hour to process all disc toll if it were done by 5 workers (400/(3*5 = 27). The replacement of the consumables does not have to be done directly at the end of a shift as long as enough the equipment is ready before the starting of the next shift.

Supposing that at moment the 2- 3 employees are planned to occupy the AFD desk by creating one extra desk 2 -3 extra workers are needed. They would be occupied for four times 30 minutes or two hours a day each. By changing work shifts one extra worker should be hired daily for every extra desk installed for the handling of the equipment. Besides the disc cutters also the pin tolls and tack machines need to be handled and in total if seems realistic to install 2 or 3 extra handling desks. In other words 2 or 3 extra workers need to be employed to occupy the extra handling desk at the AFD. The costs of reducing the allocating of the mechanical equipment is estimated to be between 50.000 and 75.000 yearly looking only at the increased cost of hiring personnel. These costs are based on the way the equipment is currently handled and administered, in the paragraph *Internet of things* the personnel costs could be reduced if a new administration system is introduced.

There will also be some costs that need to be made to create the facilities to execute this new strategy such modifications are the construction of distribution desks and extra storage possibilities. The construction of this infrastructure is estimated be no more than 15.000 Euros if 3.000 are estimated for making a new distribution desk and 5.000 for extra storage possibilities. So far we have considered only the more complex equipment and in the next section focus is put on the less complex tools.

A.5.3.2 Tools

Each worker has, once he starts working at HFG, been given a toolbox in which tools are gathered that can be used for general tasks. A distinction is made between welder and fitter toolboxes each doing activities for which slightly different tools are needed. The content of the toolboxes is checked quarterly and so far at each check a lot of equipment is found back. Especially cables, cords and equipment that need to be certified are taken out of the toolboxes during a check. Losing out of side of such equipment is dangerous and compromises the workers safety. The toolboxes might provide each worker with the possibility to lock the equipment but it does also mean that it is not transparent where equipment is which makes equipment harder to manage. Together with the cutting torches it seems useful to reduce the allocation of the toolboxes to only those workers that are actually on duty. This increases the transparency on where the equipment is and how many is available. The most common decision in similar production plants(Veth, 2011) is to use a 5S storage board to organize and store the equipment. In the figure below an example is shown of a 5S storage board.

Figure 44 5S storage board (veltion, 2013)

The board is named after a methodology of waste reduction that is used to perform lean manufacturing. It is an application of the 5S methodology that will be further analysed in the lean manufacturing paragraph. The equipment needed for one-team of production workers could be united on one 5S board and the foreman could make sure that at the end of the shift all equipment is put back into place. Using this strategy to provide workers equipment enables the foremen to adapt the storage board to the specific demand of their team. The foremen and team leaders might be able to adopt the size of the board according to the team's activities. The team in one shift will have to transfer the board to the next team that is taking over their activities and the latter will be able use the same tools. The use of the 5S board will not only means a reduction in equipment demand it will also enable provision of more specific tools for certain activities.

The employees of the AFD can make a quick visual check if the quantity of needed equipment is still up to date with the predictions made by the model. Using a 5S storage board makes it more transparent where and how many equipment is available for the production workers. The responsibility of loosing tools is no longer carried by a worker but by a whole team and at the end of the shift equipment that has not properly taken care of can be identified. The team-leaders can take actions to ensure that workers handled equipment with more care.

The installation of such board policy might be around 20.000 Euros if maximal 10 different teams are distinguished to work at once and each board cost approximately 2.000. A precise estimation cannot be given as the implementation of this board policy is linked to the implementation of lean manufacturing. The implementation of only using 5S storage boards is not very probable and the implementation needs to be done by applying lean manufacturing in parallel to be persistent. In case using 5S storage boards needs to be considered independently to only optimize the allocation factor 20.000 Euros are the estimated costs for using 5S a board.

As the implementation strategies have been considered for each equipment category separately it can now be determined what the total costs are of reducing the allocation factor. The costs of implementation are quite uncertain and the given costs estimation needs to be considered as a global estimation based on experience of the AFD. The total costs of reducing allocation for all equipment type to 67% are between 110.000 and 85.000 Euros in the first year and 75.000 to 50.000 for the years to come. An investment in lean manufacturing or administration system should further reduce the cost for changing the allocation strategy.

A.5.4 Focus on workforce

When optimizing the allocation factor it became relevant to know what the limiting factor of production pace of a platform should be. At any moment of the project people, equipment or materials could be added at extra cost to speed up the completion time of the construction. Due to the high cost of workforce in comparison to materials and equipment the limiting factor is always workers force, as is the case in many professions. The working process is adapted to the optimal working of the workforce. Materials and equipment are then considered infinite and have little influence on the optimal pace of the work process.

An example(Slack et al., 2010) is how physicians in a hospital and their work environment are managed. The environment is composed by several operation rooms in which the physician enter to only perform the operations for which he is specifically needed. The patient is put into position by supporting staff and resources are put into position during the time that the physician is working in another room. Once he is done in one room he enters the next room to perform that action for which only he is qualified. The supporting staffs takes over to make sure the room is cleaned and the patient clears the way for the next patient. The example of operation rooms being at the disposal of the workers is an extreme situation in a work field where certain qualified workers are very expensive. The construction of a platform cannot be structured with the same rigidity since the working environment is more dynamic and the actions are different that those of a specialized physician. The similarity with workers on the HFG yard is that they should be the first resource to be optimally allocated and equipment and materials are considered to be secondary to the workforce.

Once the work process is optimized around the welder, fitters and prepers the optimisation of equipment can also have an influence on the effectiveness of their work. In a hospital the used equipment is supposed to always be of the highest quality and using lower quality equipment is not an option, equipment optimization does not influence the work of a physician. At the HFG yard such high norm of equipment quality is considered unnecessarily high and useless. Using good quality equipment should still be aimed for since people with good equipment can perform better work in a shorter time. Introducing the possibility to resale equipment might make it possible to work with better quality equipment and profit of equipments' rest value. Making a cost benefit analysis to evaluate the management policy of focussing on the workforce seems difficult. The evaluation of such policy would be part of improvements focussing on the work process which is not the subject of this research. More focus on the workforce is considered realizable once the allocation has been reduced. Reducing the allocating of all equipment types creates better supervision on the quality and age of the used equipment. Adjustments on allocation might create new opportunities to further increase the effectiveness of the production process since the AFD workers are able to identify the equipment that is eligible for renewal. It seems relevant to stress the importance that equipment management can be done only after the workforce has been planned optimally and this process does not work the other way around.

A.5.5 Internet of Things

To reduce the cost made for transferring mechanical equipment a different administration method can be used. At the moment the distributed equipment is registered to the name of those who come to pick it up and use it. If the equipment is returned within a week the administered link between the worker and the equipment is removed and no administration trace is available of that exchange of equipment. Only once equipment is not returned within a week the information is registered into a computer to keep track of the transfer. Due to the fact that the information is only kept on paper for a short period of time the data cannot be used to be analysed for other purposes.

Another disadvantage of this approach of administration is that a human intervention is needed. Using technologies that are available for quite some time already could avoid the employment of extra employees for reducing the allocation factor. The user and the piece of equipment could both be identified quite fast using a scanner and software could link the two together. In 1973 bar codes were developed(Slack et al., 2010) and since then they have been largely applied in several different industries. The information that can be attributed to a bar code is limited and methods of near field communication (NFC) have been developed since the introduction of bar codes. The newer technologies are able to contain more information and are easier to read. An RFID or Radio Frequency IDentification is such a NFC technology that will communicate an Electronic Product Code (EPC) from the equipment to a scanner. The RFID technology tags an object with information readable by a scanner and these devices in a network are able to communicate between each other. This network can be called an *Internet of things* (Slack et al., 2010)as they are communicating without human intervention. An IoT enables the owner of the equipment to exactly know:

- Where things are; a RFID tag can keep track of the locations where the object has been scanned.
- What is happening; being provided with the location and the user of an object it can be deduced what is being done at the moment.
- What to do; the managers of the objects can deduce actions from the current use of equipment and plan new actions.

The implementation of an IoT would not only improve the administration of the transfer of equipment between production workers and the AFD. This administration method will create enhanced information that can be used by the management to increase the control over the work process and equipment management. To be able to use an IoT some implementation budget is needed to procure a new administration system. Knowing the exact implementation costs would require a more thorough analysis of the use of the administration system. The research of such an implementation does not fit the scope of this research project. It is considered to be beneficial to the PEMS to improve the administration of the equipment transfers. If an IoT cuts down the costs of reducing the allocation factor more than it costs to implement the administration system the latter should be implemented.

A.5.6 Lean manufacturing

As an improvement to manufacturing processes lean manufacturing is a principle or idea(Slack et al., 2010) that has gained a reputation of developing successful and effective production processes. The objective of the manufacturing philosophy is to maximize value for the customer while producing the smallest amount of waste possible. The reduction of waste creates a “lean” manufacturing process that eventually leads to cost reduction for the company. The methodology originates from the Japanese car manufacturer Toyota and principles developed by Henry Ford. Lean manufacturing can be implemented on different aspects to improve the production process. In this research focus is put on the reduction of waste measures that are prescribed in lean manufacturing literature. Waste is needed to be reduced following three strategies; muda, mura and muri which are Japanese terms for:

- Spillage; they needs to be reduced within the work process an example is the reductions of the inventories that are build up between the activities. Figure 45 shows that inventory is build up between the workstations to create a margin used if the work in one station slows down. If lean manufacturing is applied these inventories should be reduced to create a work process that is illustrated in the lower part of the Figure.
- Organizing; organizing the work planning creates a constant workflow that does eliminate large activity fluctuations. This workflow is designed optimally for an amount of work that can be handled easily.
- Overproduction; A phenomenon that in the lean manufacturing methodology needs to be avoided. Machines and personnel need not to perform more work than beyond the optimal point of effectiveness.

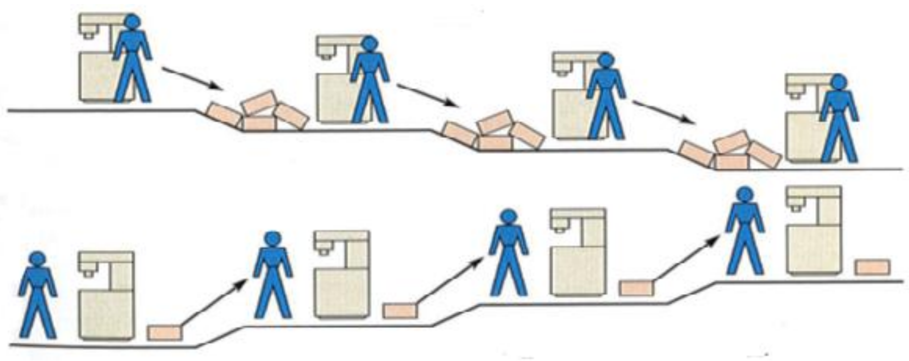

Figure 45 Reducing spillage (Slack et al., 2010)

Concerning equipment management in this research the focus is put on the elimination of spillage following the 5S methodology to rearrange the workplace of the workers in the production halls. The elimination of large workflow fluctuations is a strategy that should be applied when making the planning of the activities. Overproduction is a category of waste that also needs to be addressed but this is more a message that needs to be communicated toward the production workers and the team leaders. Overproduction can be contained if newer equipment is procured that has higher level of production capacity. To reduce spillage and improve the allocation of equipment due to less unused equipment between departments the 5S methodology should be implemented. A short description is provides an idea of what management adjustment can be expected.

Sorting; in this phase distinction is made between what is necessary and what is insignificant in the work process. All unnecessary elements of the process need to be eliminated and in practice this is an action in which old and damaged objects are discarded. The work area in the plant becomes a safer place to work in and only required equipment is put at disposition of the workers. In the sorting process the presence of each object needs to be justified and frequently used equipment should be made easily available while less frequently used equipment could be put on the background.

Straightening; this next phase of implementing lean manufacturing can be started once all objects are identified based on their necessity. Having determined the importance of each object in the workflow the object can be assigned to a specific location or position. Arranging the work, workers, equipment, parts and instructions is a procedure that leads to a workflow free of waste and enables determining the position of each object to keep avoiding the creation of new waste. Figure 46 illustrates that straightened objects are easier to count and the missing ones are identified faster.

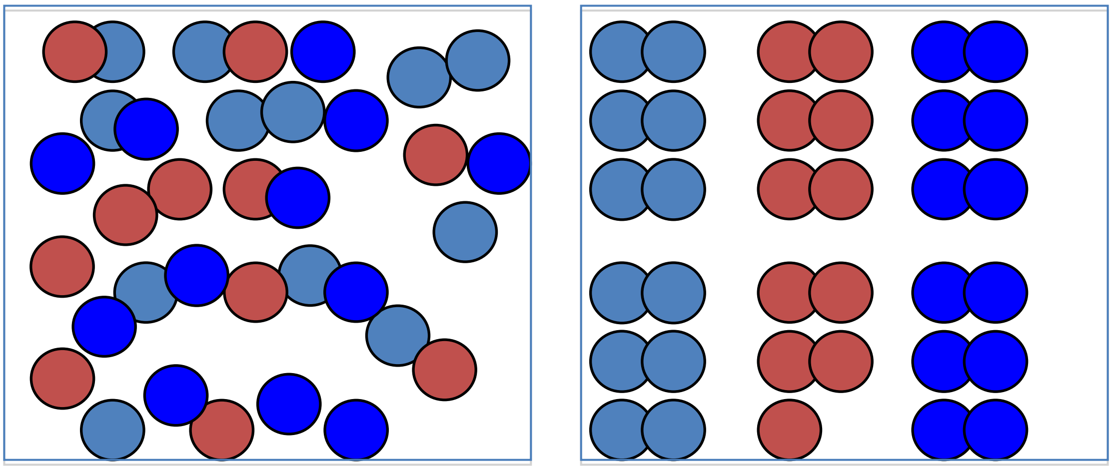

Figure 46 Lean organization (Veth, 2011)

Systematic Cleaning; in the beginning this starts with elaborate cleaning of the work area and all objects that compose it. This corrective cleanse must create a work environment that gives the workers the incentive to keep their workspace clean and tidy. As the corrective cleaning is done the work area should be cleaned preventively by identifying sources of pollution. In this phase a process needs to be designed that enable the workers to clean up their workspace and prepare it for the next user. Establishing rules, responsibilities and norms of how the cleaning should be done at the end of each shift will ensure a higher degree of cleanliness of the work area for a longer time.

Standardize; this step has to ensure that the first three phases are made sustainably and that they become a habit for the workers and their work environment. In this step methodologies are introduced that embed the first three phases of lean manufacturing into the work process. Visual tools are used to reorganize the work area using colours, lines and illustration to make the procedures understandable for everyone. This should make it clear what is normal and what not. By eliminating as much ambiguities as possible surprises are reduced and risk are contained.

Sustain: This phase has the goal to ensure disciplined adherence to the rules and procedures to avoid backsliding. This phase is a continuous one and aims to conserve the quality of the work environment at all time. With the help of checklist and audits it is observed to what degree the standardized work procedures are applied. Based on the audits and checklists the efficiency of the workflow can be evaluated. It will also enable the management to pin out specific actions in which the workers lack the application of lean manufacturing.

Once applying the 5S methodology to start using lean manufacturing the work area becomes a space that inspires the workers to work in a clean and safe manner. By attributing all objects to a specific location no objects should be left in a place where they might create a dangerous situation and compromise the safety of the work process. The 5S methodology aims to create a clarifying workspace that makes it understandable for any worker to find objects and know what he should do to perform his work safely.

Lean manufacturing does not only increase the safety of the work environment it also increases the degree in which the workers are replaceable. In some way lean manufacturing can be considered to be a strategy to improve teamwork between teams of different shifts. Leaving the work area organized and cleaned for the next worker is a sign of respect towards him. The lean manufacturing approach creates a link between the workspace and the activity that is performed in that area. The work area is the same independently of who is working there, this makes workers replaceable in order to perform the work. A new worker is able to understand how to work by observing the work area. Equipment and the workspace are no longer allocated to a worker but to an activity. And at the end of his shift the worker organizes his workspace as supposed to and enables the next worker in the next shift to continue the work while using the same equipment.

Implementing this management strategy can only be successful if it is implemented completely and accompanied with enough discipline. The discipline of ensuring that the 5S methodology is applied at the end of each shift is hard to realize as it relies on someone's personal culture to organize frequently. Some people are used to a more disorganized environment and prefer working in an environment that stays a little messy. In order to get everybody on board to realize lean manufacturing a process needs to be designed to gradually convince every stakeholder to apply lean manufacturing.

Applying a lean manufacturing strategy improves the allocation of equipment but lean manufacturing needs to be implemented from a greater perspective as not only equipment is concerned. The evaluation of implementing lean manufacturing based on its costs and benefits should be done with information that is not gathered and studied within the scope of this research. Considered to be advantageous for equipment management the cost benefit analysis cannot exactly quantify how big this advantage is. An evaluation on detailed costs of the implementation of lean manufacturing seems unrealistic with the available knowledge. More research needs to be done to determine the overall effectiveness of lean manufacturing to make a sustained decision of implementing this management strategy.