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Abstract:

Grundfos Manufacturing Hungary has undergone rapid growth since it saw the light of day in 1999. Three factories have been established in Hungary, among them GMH2. GMH2 has reached the limit in terms of available shop floor and has wished to investigate the opportunities for reaching a higher production volume by freeing square meters within the existing production facility. GMH2 assembles a fairly wide range of the Grundfos pump-portfolio and must meet the demands of the customers in terms product mix, delivery time and quality. This report seeks to present solution suggestions to GMH2 as to how square meters can be made available for additional production and at same time meet the demands of the market. Attention is directed towards removing the extensive amount of inventory present in the production. The root-causes for the inventory are highlighted; however as it turns out, the inventory partly functions as a way of coping with the uncertainties and varieties in and around GMH2. The report strives to provide solution suggestions which offer alternative flexibility-measures for GMH2 so that the organization can benefit from long-term growth. The solutions are found to be deeply rooted in simplicity and discipline, but also a realization that GMH2 self-inflicts variety on the organization by striving to "do everything all the time" instead of "doing the right things at the right times".

Foreword

This is a master thesis in International Technology Management at the Center for Industrial Production at Aalborg University. The study has been made in collaboration with Grundfos Manufacturing Hungary (GMH) and has been carried out in the time period between June 2008 and June 2009, spanning over the 9th and 10th semester of the educational program.

I would like to express my sincere gratitude to several people who have contributed to the finalization of this report.

First of all, I would like to express my gratitude towards the employees in GMH. Throughout the course of the study people have been open, friendly, and helpful and shared their knowledge. However, their contribution stretches beyond the content of this report. I have gained experiences on both a professional and personal level that I will carry with me for the rest of my life.

I would like to thank Process Manager Niels Henrik Boldvig personally, who has been the contact person throughout the study. His ideas and input have helped shape this report. Due to the numerous conversations, meetings and discussions with him over the past 10, I feel I have learned a lot from him.

Last, but certainly not least, I would like to thank my advisor PhD Harry Boer. During the course of the project he has been available with guidance, suggestions and clarifications. Even at late hours of the day he has been available, contributing with insights, perspectives and high-standard academic knowledge.

Resume/Executive summary

This report investigates the opportunities for making additional shop floor available for future production in GMH2. This is done through focusing on reduction of inventory. Currently 2250 square meters (SQMs) are occupied with inventory which accounts for 19% of the total shop floor in GMH2.

The report is initiated with an investigation of the production system in GMH2 and an explanation of the market conditions with focus on customer expectations.

The report identifies eight root-causes of the current levels of inventory:

1. The variety in products mix
2. The 12-hour delivery strategy
3. The ATO-manufacturing principle
4. Long change-over times on the machining equipment
5. Unreliable processes
6. Complex material flows
7. The undefined purpose of the internal warehouse
8. Inadequate BOMs

A discussion of the root-causes leads to the idea that the root-causes are expressions of primarily two problem phenomena which have caused the inventory to occur:

1. The inventory functions as a flexibility measure for GMH2 to match the variety imposed from the market. However, part of the variety is also *self-inflicted* e.g. the 12-hour delivery strategy. The customers and stakeholders do not expect so short order lead-time implying that GMH2 is forced to operate under uncertain conditions (increased variety) for no apparent reason.
2. The second problem phenomenon is complexity. Due to the reduced overview and transparency partly due to the extensive amount of inventory, additional inventory results from this. The saying "disorder leads to disorder" explains it pretty well. In addition, the complexity can be expected to prevent GMH2 from long-term growth.

To reduce the levels of inventory, this report suggests a range of solutions, where the need to be flexible is met by other means. In addition, the suggestions provide alternatives as to how GMH2 can reduce the variety, mainly from removing the *self-inflicted variety*.

The solutions are primarily anchored in "simplicity" and "discipline". A literary study (including empirical examinations) of the concepts proposed, suggest that organizations can be become flexible by setting up simple, foolproof, streamlined strategies, principles and procedures. These should be upheld and sustained by carrying out the strategies, principles and procedures in a disciplinary fashion which can be compared to a "set of best practices."

In operational terms, the solutions suggest that GMH2 differentiate their delivery strategy according to the MTS and MTO products. This allows GMH2 to meet the customer demands with respect to the two product categories and at the same time change their manufacturing principle from an overall ATO-principle to a MTS-principle and MTO-principle, respectively. GMH2 control the incoming flow of materials by introducing "kitting" in the internal warehouse and two simple material flows (one for MTS and one MTO) are created, allowing GMH2 to obtain overview and transparency. There are some prerequisites for the differentiated principles to be successful. The change-over times of the equipment in the machining area

(which is solely producing components for the MTO pumps) must be reduced so that only insignificant penalties in terms of capacity are obtained. This should be done by implementing flexible jaws on the integrex and multiplex equipment. In addition, capacity-planning must be initiated on the machining area so that constraints are discovered and capacity-balancing is possible.

The challenge in implementing these changes lies in the anchoring of the discipline required. The mindset and culture in GMH2 have to be altered so that everybody follows, upholds and maintains the principles and procedures. This will be a great task for the management in GMH2.

It can be expected that roughly 2000 SQMs can be made available for production by implementing the changes, in addition to open the doors for additional long-term growth. GMH2 will no longer be crippled by the complexity that inventory brings. To sum it up in one sentence:

"Instead of trying to do everything all the time, GMH2 should strive to do the right things at the right time."

Table of content

1. Introduction

This introduction will serve to give the reader a preliminary understanding of GMH2 and the context. The main purpose it to give empirical background information which assists in understanding why this study has been initiated. This chapter will present the problem area of this study and close with presenting the "Initiating problem".

General introduction

With 73 companies in 42 countries, the Grundfos Group is a heavy-weight within the pump manufacturing industry [www.grundfos.com]. With a recent acquisition of a pump manufacturer in the United States, Grundfos is now the largest pump manufacturer in the world. 16 million pumps are annually sold world-wide. The pumps are produced in one of twelve production companies which are located around the world. One location where the Grundfos Group has production is Hungary.

Expansion and growth in Hungary

The expansion in Hungary and the establishment of Grundfos Manufacturing Hungary (GMH) was started in 1999 with the establishment of GMH1. Shortly after, in 2002, GMH2 followed. Both GMH1 and GMH2 are located in Tatabánya as two separate factories on the same address. In 2007 GMH3 saw the light of day in Székesfehérvár and later that year Grundfos City was founded as a competence center in Tatabánya. From mere production sites, GMH has evolved to an independent division within the Group; with e.g. own R&D and Strategic Purchase departments. Currently around 1600 people are employed in GMH and around 600 are employed in GMH2. It is not an understatement to say that the growth of GMH has happened rapidly.

Pressures from the market

Increasing market demands, prosperous forecasts and increasing turnovers have characterized the circumstances for GMH. From a Group and GMH perspective it has been difficult not to run around with raised arms, and this is understandable. However, a few questions remain: Given this rapid growth, primarily due to market pressures, is it really possible for an organization as GMH to set up efficient thought-through processes or have things happened to fast? And what happens when the filling of order books suddenly slow down. With this growth and massive changes, one can ask: are things in GMH in or out of control?

Self examination

When approached by the author of this report, the Process Manager in GMH2 saw an opportunity to investigate and examine this issue. Concerns about the utilization of the shop floor in GMH2 were present in the mind of the Process Manager. Instead of asking the question "how can we expand?" focus was directed towards "how can we use what we got more efficiently?"

Empirical Background – focus on GMH2

Grundfos Manufacturing Hungary Ltd. (GMH) in Hungary consists of three factories:

- GMH1: Produces motors for Grundfos pumps.
- GMH2: Assembles a range of Grundfos pumps. In addition, GMH2 has in-house production (machining and painting) of a number of pump components, mainly cast-iron.
- GMH3: Produces a diverse range of components and pumps, yet cables and plugs are a substantial part of their production.

The first pump was produced in GMH2 in 2002. The pump was part of the NB range and the portfolio has later been expanded into several other pump ranges. The overall goal for GMH2 can be related to the mission and vision of the Grundfos Group: Develop, produce and sell top-quality pumps (mission) and thereby maintaining a position as one of the world's leading pump manufactures (vision) [www.grundfos.com; Executive Summary: Development of a Production System, 2003]. When setting up GMH2, one of the top priority goals was to start producing pumps as fast as possible [NHB, JTO]. This will turn out to have a significant contribution to the problem area of this report.

Organization

As GMH2 has expanded their production portfolio, so has the organization. GMH2 is part of GMH, coming to effect that certain function, i.e. Purchase and R&D, is shared between the three factories. Figure 1 shows the departments which are GMH2 departments, and the functions and areas within the departments.

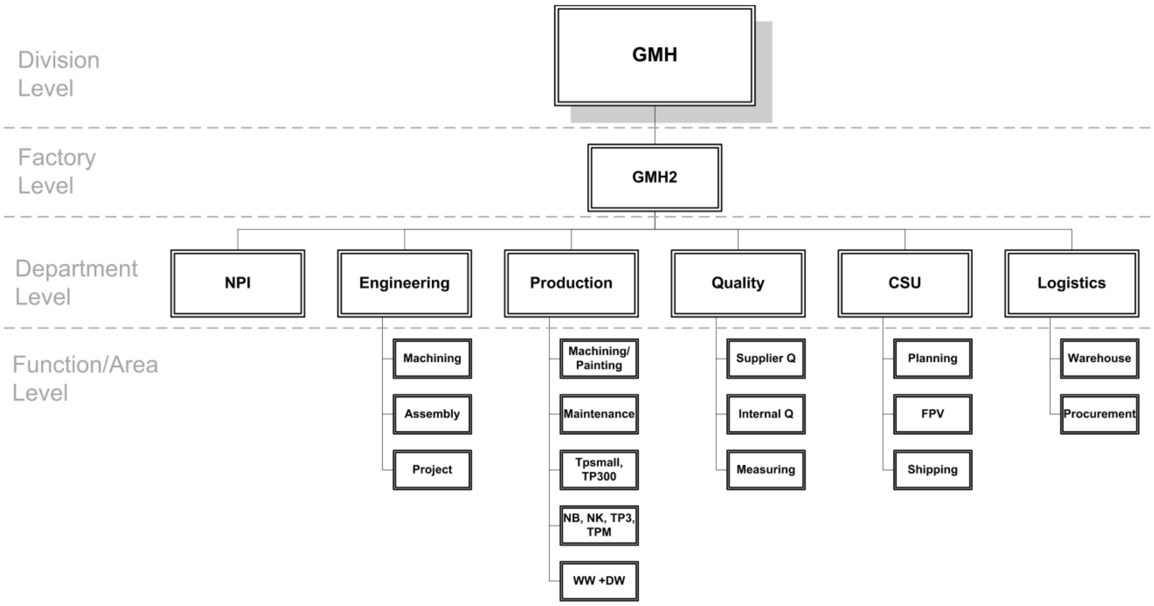


Figure 1: Organizational chart GMH2

Problem area

In terms of physical expansion (additional shop-floor space) and reaching a higher production volume, GMH in Tatabanya (GMH1 and GMH2) is approaching the limit. There are some free square meters (SQMs) between the two factories, however GMH wish to investigate the possibilities of reaching a higher production volume, by improving the area utilization of the existing production facility.

Project proposal (as presented by [NHB])

In short, the project should seek to double the area utilization of GMH2. The initial definition of area of utilization is:

$$Area\ utilization = \frac{output}{m^2} \qquad (1)$$

It is expected that the possibilities of improving both the planning processes (e.g. decreasing the planning unit from one day to few hours) and the production processes (e.g. more synchronized production of in-house components) will be investigated. Pilot projects should be implemented (where possible) to validate the overall solution suggestions.

It is expected that the project will minimum evolve around following fields:

- Lean Manufacturing
- Logistic optimization
- Operations Management/Production optimization

Expected outcome
A solution suggestion based on analysis, discussion and conclusion; which clearly identifies a feasible solution for GMH2 to double the area utilization in GMH2.

Initiating problem
In collaboration with [NHB], the following initiating problem was developed to kick off the study:

How can GMH2 double the area utilization?

2. Sphere of problem area

The purpose of this section is to discuss and define the problem area so that a clear understanding of the task at hand can be obtained and formulated in following section "Study objectives". This chapter explains a shift in focus for this study or at least focuses it on the believed "core problem" in GMH2.

What is area utilization?

GMH2 wish to investigate the area utilization, with the purpose of identifying the potential for obtaining a higher production volume. Area utilization is initially defined as:

$$Area\ utilization = \frac{output}{m^2} \tag{1}$$

During the course of this project, several possible definitions have surfaced. In appendix A1, a presentation and discussion of these possibilities can be found. On Group level and in GMH2 the following definition is now applied:

$$Area\ utilization = \frac{turno\ ver}{m^2} pr.anno \tag{2}$$

In appendix A2 this definition is challenged as an appropriate performance measurement for various reasons, but for now it is assumed to valid. The effect of solution suggestions presented throughout this report will be evaluated according to this definition.

Overview the Problem sphere

Given the applied definition of the area utilization (2), fig. 2 depicts the "sphere of the problem" area and the three theoretical ways to improve the area utilization.

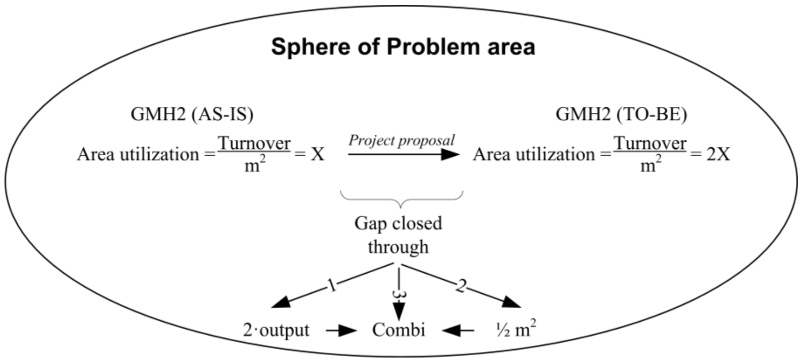


Figure 2: The sphere of the problem area and the three theoretical ways the problem can be solved

1. Approach: **Double the turnover.** If the turnover of GMH2 can be doubled i.e. "squeezing" out twice as many pumps using the current SQM, the area utilization of GMH2 can be doubled. This approach focuses on the numerator of the fraction in fig. 2, which is an expression of the purpose and goal (produce pumps) of GMH2.
2. Approach: **Reduce the used SQMs by half**. If the current output can be obtained, however from using half the SQMs, the area utilization in GMH2 would also be doubled. This approach is focusing on the constraint (SQM) in GMH2.
3. Approach: **Combination**. It can be assumed that some kind of combination can be achieved.

This constitutes a wide sphere, and several possible outcomes can be expected. However, it does make sense to narrow and focus the content of this study, due to some underlying factors of area utilization.

Why is area utilization being discussed in the first place?

If taking various definitions of area utilization aside for a moment, the project proposal was raised by the Process Manager simply because, in his opinion, the SQMs in GMH2 are poorly utilized. His opinion was backed up by the Plant Manager, and the following quotations express their concern:

> *"When I arrived here my initial thought was that we are producing in a warehouse."*
> *- Plant Manager, CUD*

> *"The storage space in GMH2 MUST be the most expensive in Hungary. The pallets are enjoying the luxury of air conditioning, heating, lighting and even decorative plants."*
> *- Process Manager, NHB*

Initial Observations in GMH2

When observing GMH2, it is striking how much shop-floor is occupied by inventory. This was one of the first thoughts that struck the author of this report when entering GMH2 in June 2008. This thought also struck the advisor of this report, when visiting GMH2 in October 2008 [Boer, visit].

It seems that the problem in GMH2 is the SQMs occupied by inventory. This affects the area utilization of GMH2 since SQMs which could be used for production activities are used for storage of components.

Coarse analysis: Area utilization

In 2007 GMH2 conducted an analysis of the area utilization and the author of this report conducted a similar analysis in 2008. Appendix B1 explains the analyses in greater detail. Table 1 shows the outcome of the analyses and Fig. 3 shows the outcome of the analyses, depicted in pie diagrams and with the values in percentages of the total shop floor SQMs in GMH2.

Analysis 2007 "Plant view"		**Analysis 2008 "Area view"**	
Production area	6.600 m^2	Equipment and V.A SQMs	*2.640 m^2*
Inventory	3.140 m^2	Inventory	*2.250 m^2*
Major roads	2.200 m^2	Major roads	*2.200 m^2*
Total shop floor	12.000 m^2	Work/walk space	*4.910 m^2*
		Total shop floor	*12.000 m^2*

Table 1: Sum-up of analyses 2007 and 2008. The difference in the findings is due to different classification of "production area" and "Equip. /V.A. SQMs

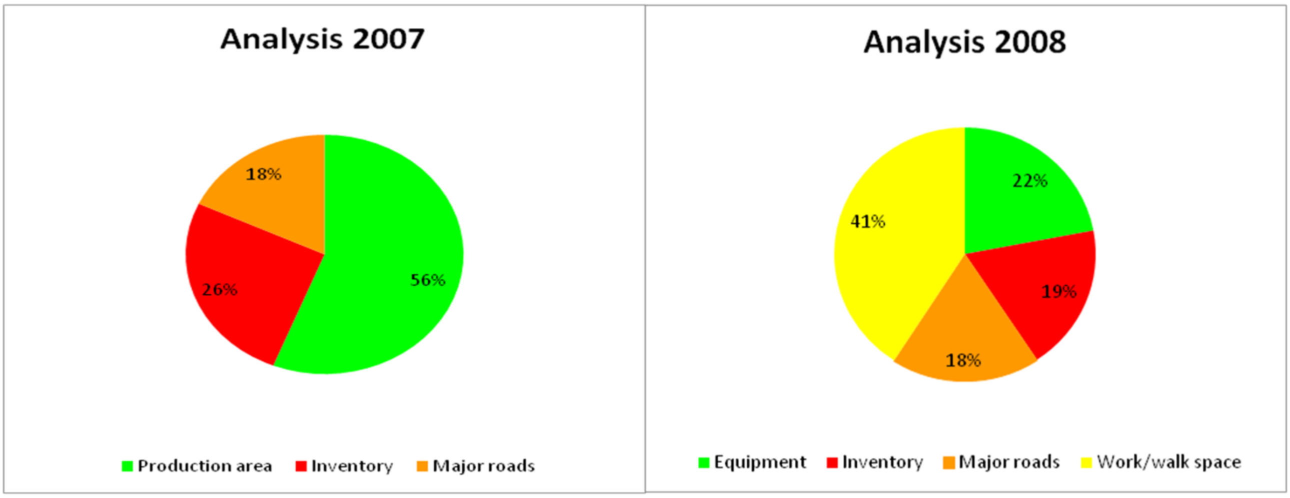


Figure 3: the distribution of SQMs as percentages of the total shop florr in GMH2

No significant changes have taken place in GMH2 between the two analyses. The difference in result is primarily due to two factors:

1.) Difference in classifications
    a. Analysis 2007 defines "production areas" as the actual production cells in the department.
    b. Analysis 2008 defines equipment and value-adding SQMs as the SQMs where actual value is added e.g. production equipment. This difference leads to a significant portion of "walking/working space" within the actual production cells.
2.) Difference in method
    a. Analysis 2007 was conducted and measured on layouts in AutoCad.
    b. Analysis 2008 was measured manually in the production department.

In the following, Analysis 2008 will be used as reference, since the classifications and method is found to be more accurate (see appendix B1). A thorough overview/comparison of the analyses can be found in appendix B2

This analysis is an expression for how the SQMs in GMH2 is currently distributed according to appropriate classifications; hence how the area is utilized. Roughly 20% (2250 m^2) of the SQMs in GMH2 is occupied by inventory, and this is not counting the SQMs (working and walking space) needed for forklifts and operators to gain access to the inventory. The outcome of this analysis supports the statements from management and the initial observations made in GMH2.

Currently SQMs occupied by inventory constitute 2250 SQMs – 19% of the total production shop floor area

Sequencing

One could argue that flow and layout considerations should be in focus, since 56% of the shop floor is used for work and walking space (see appendix B1/B2). Here the issues of sequence (order or execution) and consistency (obtaining synergies) are relevant. If an incorrect sequence is applied, inconsistency between solutions could result in wasted resources. Inventory reduction should be considered prior to layout and flow considerations. It is expected that lower inventory levels (fewer inventory SQMs) would open up for new layout possibilities. Improved flow is expected to be a tool applied to obtain lower inventory levels; hence part of the narrowed problem area.

Outside factors affecting the problem area

During the course of this study, the economic crisis has accelerated and it seems relevant to briefly discuss how this recession has affected the problem area from a current point-of-view contra the point-of-view in May/June 2008 when the project proposal was formulated.

Market

From a market perspective the circumstances have changes for GMH2. GMH2 was expecting growth in 2009 of all (except TP400) produced pump ranges. Table 2 shows the forecast for GMH2 up till 2012.

Profit center	2008 [pcs.]	+/- %	2009 [pcs.]	+ %	2010 [pcs.]	+ %	2011 [pcs.]	+ %	2012 [pcs.]
TP100-200	**26.000***	10	**52.282**	6	**55.310**	6	**58.834**	6	**62.585**
TP300	**51.300**	15	**58.993**	16	**68.215**	16	**79.008**	16	**91.719**
TP400	**480**	-20	**384**	-30	**269**	-40	**161**	-80	**32**
NB	**23.860**	10	**26.282**	10	**29.040**	10	**32.004**	10	**35.277**
NK	**8.000**	24	**9.955**	11	**11.022**	10	**12.161**	10	**13.422**
SE	**12.800**	10	**14.080**	24	**17.459**	21	**21.126**	20	**25.351**
SL	**N/A****		**5.720**	60	**9.200**	20	**11.040**	20	**13.248**
SEP	**6.800**	17	**7.956**	38	**10.979**	15	**12.626**	10	**13 889**
SEG	**16.500**	12	**18.480**	38	**25.502**	18	**30.093**	15	**34.607**
DW	**600**	100	**1.200**	15	**1.380**	15	**1.587**	15	**1.825**

Table 2: The original forecast and expected growth of produced ranges

Demands have dropped to around 80% over the last months and the budgets for 2009 have been adjusted [CUD, weekly presentations]. Expected sales and growth in 2009 is not being realized; hence making the forecasts invalid. The forecast was a prime argument in September 2008 for investigating and improving the area utilization in GMH2, and focusing on obtaining a higher output. However, it is important to state, that the forecast is not “wrong” per se. One can argue that it has merely been postponed. Yet it still has some consequences. One of the arguments for improving the area utilization was directed towards the nearby increasing demand of the currently produced pumps. This need is no longer urgent.

Financial

From a financial perspective, liquidity has suddenly become a key-issue for companies such as the Grundfos Group. Heavy (aggressive) investments, e.g. expansion in Serbia [Grundfos Insite], have been put on hold. Even more conservative financial policies and strategies are put in place throughout the Group. This is partly due to cost-saving initiatives, but another opportunity allures in the horizon. Competitors are also affected by the Crisis, and companies with less healthy economic foundations might collapse due to the pressure of the Crisis. This might present the Group with opportunities to acquire new technologies, market openings and shares [JTO, CB monthly update]. There are therefore several incentives to uphold a substantial cash position, and strike when a favorable situation presents itself. How does this affect the problem area? Investments in solutions become a constraint. Budgets throughout the organization are tightened even further. GMH2 is not looking for high-end “Rolls-Royce” solutions. The sentence “the cheaper, the better” sums it up pretty good. Even though a return-on-investment (ROI) analysis show a pay-back period of X years which, under normal circumstances, would have been accepted, this is currently not the case. Liquidity has become an issue and cash investments a constraint.

With these factors in mind it is possible to clearly define the objectives of this study.

3. Study Objectives

The purpose of this chapter is to clearly pinpoint the problem which is under investigation and present the relevant working questions which will be answered in the conclusions.

Pinpointing the problem and revised initiating problem

The problem in GMH2 is the amount of SQMs occupied by inventory, whether that being raw materials or WIP. This comes to show by the statements made by management and the observations made in GMH2. These are backed up by the results of the coarse analysis: area utilization. It seems appropriate to focus this study on solving this exact problem. By freeing SQMs, through inventory reduction, strategic decisions, depending on the market situation, can be made whether the unused SQMs should be used for production of the existing ranges or if new pump ranges should be introduced in GMH2. This will in effect improve the area utilization as defined in (2). The report should keep in mind that liquidity is an issue and needed investments should be considered carefully. The following question more accurately describes the problem at hand:

How can the SQMs occupied by inventory in GMH2 be reduced?

Working Questions

In order to investigate the problem at hand the following working questions have been established. The questions have been divided into two parts, where the first set of questions investigate the current situation at GMH2 (AS-IS) and the second set of questions is directed at providing solution suggestions for GMH2 (TO-BE)

Working Questions Part 1:

1. What are the SQMs occupied in GMH2 by inventory?
2. How is the production system in GMH2 set up?
3. What are the root-causes for the current levels of inventory?
4. What purpose does the inventory serve in GMH2?

Part conclusion: Clear understanding of inventory present in GMH2 and an understanding why it has occurred.

Working Questions Part 2

5. What are the possible solutions to the root-causes?
6. What will be the effect on the SQMs and area utilization?
7. How should the solutions be implemented?
8. What are the benefits and expected costs of the solution suggestions?

Conclusion: Clear solution suggestion showing what changes GMH2 has to make to reduce the amount of SQMs occupied by inventory.

4. Study Design

The purpose of this section is to provide insight in terms of the methodological steps taking during the course of the study. The chapter strives to provide evidence that the study has been carried out in manner which meets the academic standards required. In addition, it strives to highlight the logic behind the study to give the reader an opportunity to evaluate the sequential steps taken.

An important note

This study's methodological design is primarily based on the case-study research strategy as presented by [Yin (2002)]. It is important to state that this study should not be classified as "research". This study investigates a contemporary problem within a case company and strives to propose a solution suggestion, which (if implemented) can assist the case company in solving the problem. Nevertheless, a case-study research design, as described by [Yin (2002)] is a way of describing the methodological steps taken throughout the study [Boer & Lassen, AAU] in order to:

a. Demonstrate the "value" of the study for practical and academic purposes
b. Provide a basis for applying it
c. Allow for external judgment to be made about the consistence of procedures and the neutrality of its findings and suggestions [http://www.gifted.uconn.edu/siegle/research/Qualitative/trust.htm]

Case study

This study is *case-study* carried out in time period June 2008 to May 2009. When conducting a case study, there are five key elements which should be highlighted [Yin (2002)]:

1. Research questions (in this case working questions)
   - "How", "why" or "what" questions. Indicate the problem area.
2. Research propositions or purpose (in this case purpose)
   - Often derived from the above questions and directs the study.
3. Unit(s) of analysis
   - Definition of the case.
4. The logic linking data to the purpose
   - The logic behind the analytical framework
5. The criteria for interpreting the findings and solution
   - Related to the establishment of "trustworthiness" and "practicability" (will be elaborated later) in study.

Working questions

Initially, the question in focus is the proposed initiating problem. The problem reads:

How can GMH2 double the area utilization?

However, as argued in "Sphere of Problem Area" and presented in "Study Objectives" the problem in focus for the study can more accurately be described as:

How can the SQMs occupied by inventory in GMH2 be reduced?

The concept of area utilization is not abandoned. It is argued that if the SQMs occupied by inventory are reduced and if replaced with value-adding SQMs, the area utilization as defined in (2) will also increase.

To investigate the problem sphere, following working questions have been established in "Study Objectives":

Part 1: Diagnostic

1. What are the SQMs occupied in GMH2 by inventory?
2. How is the production system in the case company set up?
3. What are the causes of the current inventory levels?
4. What purpose does the inventory in GMH2 serve?

1-4 will be investigated in Part 1 of the report and explicitly answered in "Conclusion Part 1".

Part 2: Solution development

5. What are the possible solutions to the root-causes?
6. What will be the effect on the SQMs and area utilization?
7. What are the costs and benefits of the solution suggestions?
8. How should the solutions be implemented?

5-8 will be investigated in Part 2 of the report and explicitly answered in "Conclusion Part 2"

Purpose

The purpose of the study is to analyze the production system of GMH2, mainly from an Operations Management perspective, where the processes, procedures and set up are under investigating to discover the causal relationships for the current inventory levels. Provided that the root-causes can be identified, a solution suggestion will be developed, which illustrate a "sound" (will be elaborated later) alternative where the SQMs occupied by inventory is reduced.

Unit of analysis

The unit of analysis is GMH2 which include the departments:

- Internal warehouse
- Production department
- CSU department (planning)
- Procurement/Logistics
- Quality/Engineering

Two additional organizations will be mentioned throughout the study. The external warehouse and the distributions centers (DCs) are considered supplier and customers, respectively. It is important to mention that the external warehouse operates closely with GMH2 and a strategic partnership is a possibility [AWE]. The DCs are Grundfos owned.

The logic linking data to the purpose

The purpose of this study has two dimensions that are sequential:

1. Identify the root-causes of the current inventory levels
2. Develop "sound" solution suggestions for reducing the SQMs occupied by inventory.

This entails that the "logic" will have two parts as well, and be sequential; hence matching the purpose. The following steps can be mentioned:

Part 1: Diagnostic

1. Analytical framework: The “blueprint”/required steps for identifying the root-causes
2. Data selection: What data is needed according to the blueprint? [Lassen (2008)]
3. Data collection: How is the data collected? [ibid]
4. Data analysis: How is the data applied to the blueprint? [ibid]
5. Discussion and findings: How are the analyses interpreted (AS-IS scenario according to problem area)

Part 2: Solution development

6. Establishment of “Best practice”: What characterizes the TO-BE scenario?
7. Solution suggestion: How can GMH2 move from AS-IS to TO-BE?

Fig. 4 illustrates the logic.

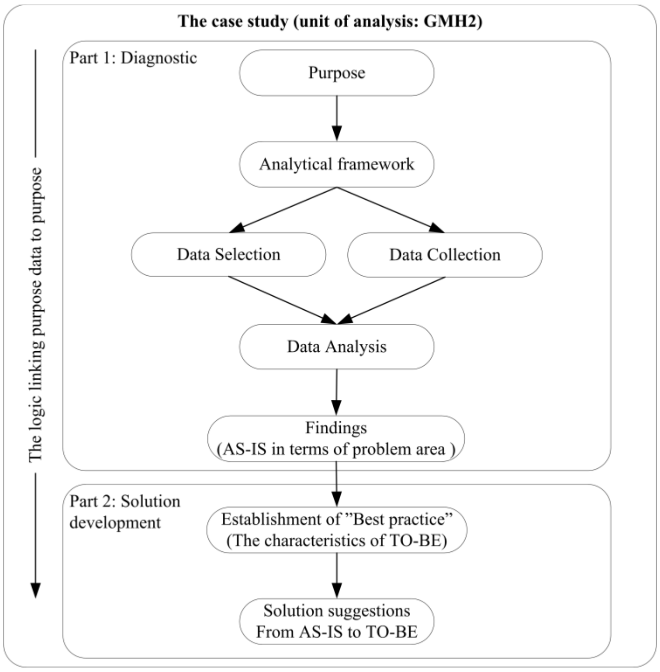


Figure 4: Illustration of the logic linking the data to the purpose

Analytical framework

The analytical framework for the diagnostic and understanding AS-IS consists of the three primary bodies of literature:

1. Value-Stream-Mapping
2. Problem solving/identification
3. Operations Management/analysis of production systems

In addition two key terms are defined and applied in the discussion of the diagnostic. “Flexibility” is derived from operations management as well. “Variety” is defined during conversations and discussions with the advisor of this report, Harry Boer. The analytical framework is described in fig. 5.

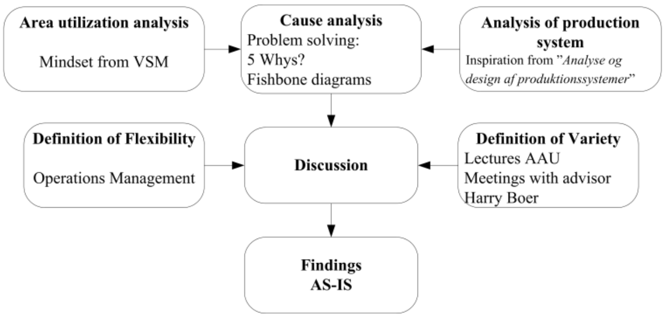


Figure 5: The analytical framework

Area utilization analysis

Given the problem at hand (inventory) and the constraint (SQMs) an analysis showing the amount of inventory present is an appropriate starting point.

Analysis of production system

In order to obtain an understanding of the unit of analysis, a descriptive analysis of the production system will be constructed. Focus will be on selected characteristics which are expected to have an impact on inventory, based on thorough knowledge in the field of operations management.

Cause analysis

The study will strive to identify the root-causes of the inventory levels in GMH2. This complicated task will be assisted by the use of the Six Sigma tool "5 whys" and fishbone diagrams.

Data selection

Based on the analytical framework, two questions are sought answered:

1. What data is required?
2. Which informants can provide the data?

Required data

As a logical consequence of the complex problem sphere, the diversity of the working questions and in effect the wide analytical framework, the data must match this complexity. This implies that data is selected from practically all departments in GMH2 in order to conduct the required steps. In addition, since the problem sphere entails strategic considerations as well as operational considerations, data from the different hierarchical levels must also be included as well. One way to put it: The "depth" and "width" of the analytical framework (as a consequence of the depth and width of the problem sphere) must be match with "depth" and "width" in the data selection. Fig. 6 shows the "width" and "depth" of the data selection:

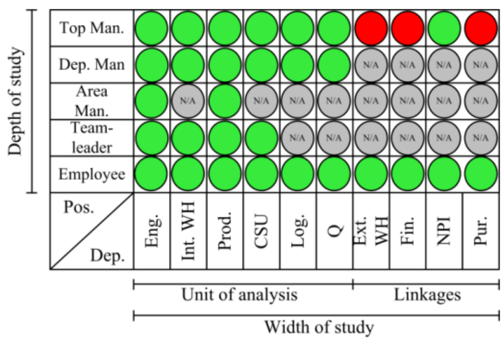


Figure 6: The depth and width of the data selection

The grid shows possible "locations" of data selection. The green circles indicate locations from where data has been selected. Grey circles indicate "unavailable locations" since the positions are not applied in the respective department. Red circles indicate positions from where data has not been selected. It is important to mention that the circles in fig. 6 are <u>not</u> expressions of informants (one circle = one person). The figure is merely an expression of "locations" where data has been selected; hence the "width" and "depth".

Selecting informants

In terms of selecting informants, informants with "hands-on experience" regarding the subject under investigation have been preferred. The following approaches were applied:

1. The contact person [NHB] was approached with the question: "Who works with this subject or who has extensive knowledge about this?"
2. The manager of a given department was approached with the same type of question
3. During the course of the study "go-to" informants were identified. Primarily based on their working experience in GMH2, previous work assignments etc., they posses extensive knowledge in regards to "who knows what?" Among these "go-to" guys [GSA], [MC], [LKI] and [GAR] can be mentioned.

Data collection

[Yin (2002)] identifies six different sources of data in the case study research strategy:

1. Documentation
2. Archival records
3. Interviews
4. Direct observations
5. Participant observation
6. Physical artifacts

This study makes use of all of the above as shown in table 3. Some percentages are allocated the different categories to give an idea how heavy the approach weighed in the overall data collection.

Documentation and records (evaluated weight: 25%)	
Source	*Examples of data*
Common drive	**Weekly presentations (KPIs), layouts, process description, etc., lean material, performance measurements, sales, forecasts**
Insite (intranet)	**Organizational overview, concepts and programs**
SAP	**Avg. order sizes, SAP routings (throughput times), financial information**
www.grundfos.com	**Product information**
BE-material	**Concepts**
Lotus notes database	**Delays of materials, BOM problems**
OEE database	**OEE measurements**
Interviews (evaluated weight: 60%)	
Type	*Examples of data*
Focused based on interview-guide	**Information regarding departments, areas and processes.**
Open-ended based findings	**Status-presentations, discussion workshops, presentation of findings**

Survey-based (questionnaire)	**A questionnaire was personally delivered to 50 employees asking their opinion about the relationships between departments in GMH2**
Direct observations and physical artifacts (evaluated weight: 10%)	
Type	*Examples of data*
Observations in production department	**Measurement of SQMs for Area Utilization analysis, investigation of inventory levels, KANBAN system, "inspirational" walks**
Pictures	**Numerous pictures were taken in the production department**
Participant-observations (evaluated weight: 5%)	
Type	*Example of data*
Process development meetings	**Information about six sigma, lean and BE programs/concepts**
Departmental meetings	**Performance measurements**
Kaizen event "Impeller cell"	**Information regarding the processes in Production, lean**
Kaizen event "Warehouse"	**Information about the logistic issues**

Table 3 : Different sources of data collected

Data analysis: Connecting the analytical framework and the data.

Area utilization

For the area utilization analysis, the mindset of VSM has been applied. During direct observations in the production department with [NHB], the idea was suggested by the author of this report. The rationale is that SQMs should be value-adding in the sense that value-adding activities should be performed on the SQMs. Several attempts had been made in GMH2 to measure the area utilization; however the classifications used previously had not *really* expressed the area utilization.

In terms of the area utilization analysis, the data regarding the SQM ratios (collected through direct observations) were plotted on the CAD-layout of GMH2. The plotting of data results in several area-maps and an overall map of GMH2 showing the allocation of:

- Product equipment and stations (value-adding SQMs)
- Major roads (non value-adding SQMs)
- Walking/working space for operators and forklifts (non value-adding SQMs)
- Inventory (non value-adding SQMs)

Descriptive analysis

For the descriptive analysis, a framework describing key elements of the production system was needed. Several models e.g. McKinsey's "Seven S model", Galbraith "5 star model", etc. can useful for describing the organizations. However, in terms of production systems, it is found that the framework [Johansen et *al* (2006)] is very useful. The framework originates from the ViPS (Virksomhedstilpasset Produktionsstyring) research program aimed at assisting companies in developing or improving existing production systems [ibid]; an umbrella under which this study can be classified. The author of this report is familiar with the mindset from ViPS and has applied several tools and methods e.g. problem-matrices and problem identification with success previously.

In terms of the data collected for the descriptive analysis, it will be "inserted" in the framework developed and provide a basis for understanding. The descriptive analysis strives to give a trustworthy representation and understanding of GMH2. One can argue that the descriptive analysis is a mere representation of the data collected, however in a well-thought, “digestive”, and structured manner. This representation allows for overview of the system

Given the descriptive/illustrative nature of both the area utilization analysis and the descriptive analysis, the steps taken are very representative in nature. They serve to provide a basis for the cause analysis as described in the analytical framework.

Cause analysis

The cause analysis strives to “make sense” of the data presented in the descriptive analysis and how it is linked to the inventory levels discovered in the area utilization analysis. “5 whys” and fishbone diagrams were used as problem identification tools. Determining root-causes are often a complicated task [ibid] and a systematic, structured and illustrative approach can with benefits be applied. During the course of this study, workshops with relevant personnel from various departments have been conducted in order to develop these cause-effect relationships. Input from a production, quality and planning point-of-view is required simultaneously in order to understand why problems occur since the causal relationships often span various departments. It can be summed, that the cause analysis takes the “analytical” steps based on the representation of the data in the two previous analyses.

Establishment of “Best Practice”

“Best practice” is established through a literary study on mainly the key-word “flexibility” and “order-penetration-point” (OPP). Based on the findings of the diagnostic it is assessed that these two terms represent cornerstones in the development of solution suggestions. This will be highlighted in the discussion and conclusion of part 1.

Solution suggestions

The solution suggestion will give suggestions to how the root-causes are removed with foundation in the established “Best practice”. In addition, a suggestion for an implementation sequence. The solution suggestions will present the expected gains and to the extent possible the expected costs. It should be seen as an indication of whether the solution suggestions are feasible.

The criteria for interpreting the findings of Part 1: Trustworthiness

Given the findings throughout the study, the concept of “trustworthiness” derived from [Lincoln & Guba (1985)] is applied. The purpose of establishing “trustworthiness” is that the findings are “worth paying attention to” [ibid]. This is done with focus on the following four issues:

1. *Credibility*
    - Assessing whether data has been interpreted in a “credible” way by the author of this report.
2. *Transferability*
    - Assessing whether the findings can be applied outside the unit of analysis. This point is not addressed since the case study’s purpose is purely to solve a problem within the unit of analysis.
3. *Dependability*
    - Assessing whether a similar study in GMH2 would yield the same findings. (It can be argued that if the study has credibility, it must have dependability).
4. *Confirmability*
    - Assessing the degree to which the findings are supported by the data collected.

Establishment of trustworthiness

A number of steps were taken throughout the diagnostic to ensure trustworthiness.

1. Prolonged engagement
   - One way to ensure *credibility* is by prolonged engagement [Lincoln & Guba (1985)]. The author of this report had the opportunity to be in the case company for 10 months, get familiar with the organization, the context and the employees and develop an understanding and critical sense for the data selection and collection.
2. Triangulation
   - In terms data collection, a triangulation was always attempted to ensure *credibility* [ibid]. Data required in e.g. interviews sought verified with data from the common drive, other sources and by asking slightly different questions. In addition subjects were discussed with people from various departments providing different perspectives.
3. Peer debriefing
   - In terms of this study, peer debriefing was an opportunity. The 10 months were spent with a fellow student. Ad hoc topics, questions and issues could be discussed with an peer, creating a chance to see weaknesses or flaws in the analytical steps
4. Overlaps
   - To ensure *dependability* especially the findings of the study was presented several times to employees, area managers and top managers. Status presentations and "presentation of findings" meetings were held numerous times over the 10 months period. Among the most noticeable, two status presentations were conducted for the management team. In addition, workshops with relevant personal were conducted over several weeks to discuss findings and provide input.
5. Data reconstruction
   - This report should assist in establishing *confirmability* of the study by providing a step-by-step overview of the course of the study, including a thorough discussion of findings. In addition, all collected data has been made available on common drive for future reference and use in GMH2.
6. Advisor meetings
   - Also to ensure trustworthiness, the advisor of this report has been contacted continuously throughout the course of the study and briefed about ideas, steps and approaches. The advisor has proposed suggestions and guided the study.

The criteria for selecting the solution suggestions of Part 2: Practicability

As mentioned previously, the purpose of the study is to develop "sound" solution suggestions. The solutions presented in Part 2 will be interpreted slightly different than the findings of Part 1. This will be based on [Boer, meeting]:

1. *Compatibility*
   - The solution suggestions must "match" the case company in the sense of the characteristics, skills, technologies knowledge.
2. *Consistency*
   - There must be consistency from a strategic point-of-view to an operational point-of-view. This means that the solution suggestions must take into account that processes and procedures support the concepts, and the concepts support the strategy; hence creating consistency.
3. *Feasibility*

- As mentioned liquidity is an issue, hence making feasibility of the solution suggestions even more important. To the extent possible, a cost-benefit analysis should be included to assist the decision makers.

4. *Robustness*
    - It should be addressed how robust the solution suggestions are and what degree of maintenance, follow-up, etc. should take place when implemented.

These issues will be addressed in the discussion of the solution suggestions. Any kind of mismatches or necessities will be highlighted and addressed.

Important limitations

Time constraint and nature of solutions

During the course of the study some limitations have been required. The primary reason is the time-constraint. The study was carried out over 10 months and given the large unit of analysis, the study did manage to include implementation/test of solution suggestions. Another factor contributes to the missing implementation. The suggestions take a starting point with some strategic/conceptual changes. The purpose of this study will be to illustrate why and how the proposed changes will decrease the SQMs occupied by inventory.

The level of detail

Again relating to the large unit of analysis, the report will operate on an overall/”conceptual” level. To give an example which illustrate the point: If discussing the KANBAN system, this study is not intended to investigate the sizes of the KANBANs, it is intended to discuss whether the KANBAN system is needed in the first place? In some cases it makes more sense to go into greater detail for illustration and argumentation purposes. This of course will be done.

The inventory in external warehouse not investigated

The inventory in the external warehouse has not been included in the unit of analysis. When referring to the external warehouse, the reference is to TransPoint, a third-party logistics supplier (3PLS). The reason the 3PLS is included is that it actually simplifies the upstream supply chain. Materials are expected to be delivered to TransPoint providing some beneficial opportunities which will later be described. It can be stated that the *internal* supply chain is investigated with the purpose of reducing the need for inventory. It can be stated that the “link” is investigated, but not the organization itself.

The inventory in the DCs is not investigated

Whether the inventory levels in the DCs can be reduced, or whether the replenishment system can be improved will not be investigated in this study. There are indications, that a more integrated system/supply-chain view would assist GMH2 with respect to inventory problems. The organizations within the Group seem to operate in a very independent manner, and it could be expected that problems could be solved from a more integrated approach. Again, reference may be made to the links to the DCs, however the organization itself is not investigated.

The modular design of the products are not investigated

The modular design of the pumps produced will not be investigated in this study. There are some indications that the modules can be questioned. The many part-numbers of the same component within each pump range could indicate that the modules could be improved.

The C and D products are not in focus

The C and D products (variants where components are not kept on stock) are not included in this study. The C and D products account for 8% of the total pumps sold.

The inventories of packaging materials

The inventory of packaging materials is not investigated in this study due to time constraints. However, given the amount of SQMs occupied by packaging materials, there are certainly indicators that the flow could be improved.

The aspect of change management

The aspect of change management will only be touched briefly in the discussion of the solution suggestions. However, primarily due to experiences from the lean program it is important to stress that GMH2 should consider some change management initiatives to ensure change processes are successfully completed.

5. Analytical framework for Diagnostic

The following chapter strives to provide insight in underlying theories utilized in the first part of the study. The theories will be briefly described and so will the way they are applied.

Area utilization analysis

The area utilization analysis was conducted with inspiration from Value-Stream-Mapping (VSM). VSM is probably one of the most famous tools from the “lean toolbox”. In short, VSM is an approach where the *value stream* is mapped with focus on identifying the *value adding* processes and *non-value* adding processes. Identification of these two categories will provide the first step for organizations to eliminate or minimize the *non-value adding* processes which, in lean terminology, is classified as waste [Rother & Shook (1999)].

This mindset is applied in the area utilization analysis. When investigating the SQMs in GMH2, the basic question throughout the analysis is: “Does the activity taking place in this area add value?” By mapping the value adding SQMs vs. the non-value adding SQMs, the area utilization of GMH2 can be presented based on a lean/VSM-mindset. This is a useful categorization of the SQMs in GMH2, since it must be assumed that it would be useful for GMH2 to reduce non-value adding SQMs and replace them with value-adding SQMs; hence improving the area utilization.

Descriptive analysis

The framework for analyzing and describing GMH2 has been inspired from work of [Johansen et *al* (2006)]. The work contains a 10-step approach for setting up production systems. With inspiration from these ten points, the following points will be investigated:

- *Background and history*
  - The background/history of organizations provides important input in the understanding of organizations. Conditions inside and outside of the organization change over time and may cause some inequalities and mismatches. (This point has been covered in the empirical setting.)
- *Delivery and manufacturing strategy*
  - Some of the strategies in place will be highlighted since they will an impact on the production system and the set up.
- *Concepts and programs*
  - The concepts and programs currently running in the organization should be considered, especially in the solution development phase, to ensure consistency and obtain (possible) synergies.
- *Product characteristics*
  - An overview of product ranges, variants and the MTS/MTO ratios is needed when investigating the problem area to understand the demand circumstances. It is expected that especially and MTS vs. MTO ratios are important when focusing on the levels of inventory.
- *Production set-up*
  - A clear picture of the different areas, inventories and decoupling points in the production is required in order to understand the internal supply chain.
- *Production processes*
  - An understanding of the characteristics of the processes, e.g. high vs. low volume production and change-over times is required to put forth valid suggestions.

- *Production planning*
  - The current approach of production planning will be investigated to discover improvement possibilities for reducing the levels of inventory.
- *Logistics*
  - The set-up regarding incoming goods and how the finished pumps are leaving the GMH2 should be considered in the solution suggestions.
- *Suppliers*
  - In addition to the processes, an understanding of the suppliers should be obtained an included.
- *Customers*
  - The market requirements should be investigated and the solution suggestions should take these into consideration.

From the above points, it should be clear that not only the production system, but also linkages to other parts of the organization (e.g. planning) and the environment (e.g. customers and suppliers) is under investigation. A holistic understanding of the production system and its context is required to put forth consistent and valid solutions. These linkages affect the requirements and tasks of the system and should therefore be included [ibid].

Cause Analysis

A common problem in organizations is fire-fighting. Resources are spent solving what is referred to as "symptoms of problems", instead of the actual root-causes of the problems [ibid]. It is the authors opinion, that one of the drivers for this misuse of resources, is that organizations are often under pressure (due to time, resources or stakeholders) to find quick-fixes which yield fast, visible results (preferable on the KPIs or bottom-line). The consequence of this fire-fighting is that problems reappear or are covered up (e.g. by inventory). Determining the root-causes of problems can be a time-consuming process, and often requires input from several sources. The complexity of the task can be overwhelming. Here the cause-effect/fishbone/Ishikawa diagram is an excellent tool [ibid]. Combined with the Six-Sigma tool "5 Whys" the underlying causes can be understood and illustrated [MC, Insite].

Variety

A term which will be mentioned throughout the analyses is "variety". Several meanings can be attached to the term variety: Changing market needs, uncertainty, volatility, internal variation, **[**da Silveira (2005), Slack (1983), Slack et *al* (2007), Upton (1994), Olhager (2003)]. The interpretation used throughout this report may not be a "textbook definition"; however it is the interpretation of variety which has characterized the conversations and discussions between the author and advisor of this report during the course of the project. Variety takes a few different meanings throughout the analysis, yet with the common characteristic that as a consequence, GMH2 experiences uncertainty.

Internal variety

Internal variety is related to the strategy, procedures, operations and processes in GMH2. Depending on how these are set up, controlled or executed, variety may happen as a consequence. An example can be an unreliable process due to breakdowns. GMH2 will experience variety in terms of throughput time and perhaps quality, hence leading to uncertainty.

External variety

External variety is primarily related to the customers of GMH2. Variance in demand-mix and/or demand-volume puts GMH2 in an uncertain position. Requests for customization are the best example of external variety.

Imposed vs. self-inflicted
As mentioned changes in customer demands impose a big category of external variety. This kind of variety is *imposed* on GMH2. The market simply demands customization and GMH2 has to react to this. However, variety can also be *self-inflicted*. By setting up processes or procedures that result in variety, and actually not important/valuable for the customers GMH2 inflicts variety (or forces) themselves to operate with uncertainty. It will be argued later in the report that the 12-hour delivery strategy is *self-inflicted* variety. Customers do not expect this, yet the production system in GMH2 has been set up accordingly.

Flexibility

Numerous scholars [Slack (2005), Boer (continuous meetings and lectures), Upton (1994), da Silveira (2005)] agree that flexibility is the "antidote" for variety. First of all, a definition of the term flexibility can be useful: *"The ability to change or react with little penalty in time, effort, cost or performance"* [Upton (1994)]. As often the case in business/management-engineering litterateur, concepts like "flexibility" carry a degree of ambiguity (other examples include: value, capacity, etc.). The definition mentioned here entails that flexibility is an expression of three elements.

The first element is *flexibility as an expression of range* of different outputs an organization can accomplish. Examples are: product variants, volume, delivery, etc. [Slack (1983), Slack (2005a), Upton (1994)]. Several taxonomies exist for describing different types of flexibility [Upton (1994]. One of the prevailing taxonomies is actually one of the first, presented by Nigel Slack in some of his early works regarding flexibility. Four categories were presented [Slack (2005a)]:

- *Mix flexibility*: The ability to produce a varying product mix.
- *Volume flexibility*: The ability to produce according to changing customer demands.
- *Product flexibility*: The ability to introduce new product variants.
- *Delivery flexibility*: The ability to deliver to customers as requested.

One additional type of flexibility will be mentioned, since it is important in the context with GMH2 (a common problem, with pre-described taxonomies, is that "local" needs and requirements may be left out [Upton (1994)]). The type of flexibility which will be included is:

- *Process flexibility:* The ability to produce according to alternative routings.

[Slack (2005a)] actually addresses this type of flexibility, but argues that it is a mean to obtain one of the four above mentioned flexibilities. The author of this report agrees, however it is explicitly mentioned and highlighted here since it is very important in the context of GMH2.

The second element is *flexibility as an expression of "how efficient"* (resources and/or time) an organization can change from one part of the range to another [Upton (1994)]. E.g. how fast and at what cost a new product variant can be introduced, how fast and at what cost a delivery date can be changed, etc.

The third element is *flexibility as an expression of "uniformity".* When shifting from one part of the range to another, performance measurements, e.g. quality, product price etc., should not be affected [ibid].

Fig. 7 sums up how flexibility is viewed in this report.

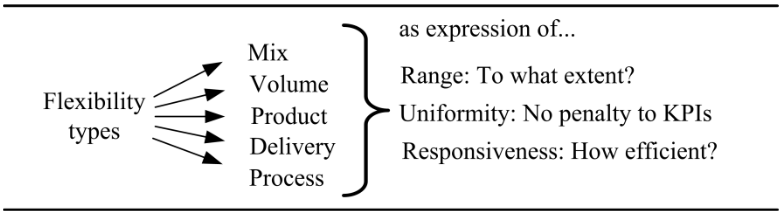


Figure 7: The definition of flexibility used in this report. Adapted from [Slack (2005a)] and [Upton (1994)]

Sum up

After an exposition of the framework for the diagnostic, fig. 8 is (re)presented as a sum up for how the theories, tools and definitions will be used in context with each other

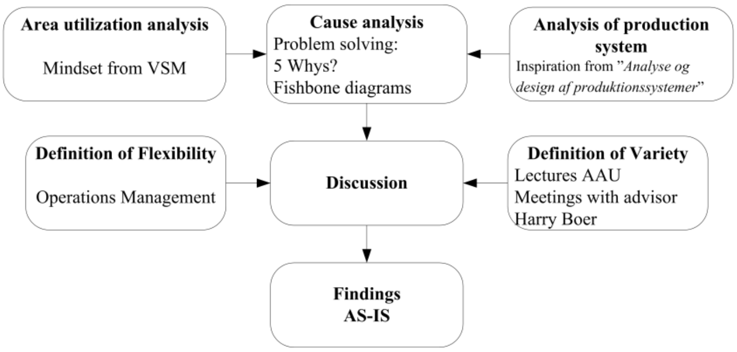


Figure 8: The analytical framework for the study

A thorough discussion will follow the analysis where the findings will be addressed from different perspective and in context with each other. Based on this discussion, a part conclusion for the diagnostic will be presented.

6. Descriptive analysis

The purpose of this section is to give insight in the production and supply-chain (SC) set-up in GMH2. In addition, the different processes in and around the production will be described. The section will serve to explain GMH2 and its context and provide input for further analysis and discussion.

GMH2

Delivery and Manufacturing strategy

As mentioned in the empirical setting, in 2001 there was pressure from the market and stakeholders to start producing pumps *"as fast as possible"* [JTO, NHB]. It was chosen to set up the production of pumps on a 12-hour delivery strategy, meaning that when a customer order enters GMH2, the pump should be able to leave GMH2 within 12-hours. This led to an assembly-to-order (ATO) principle. In-house machined components would be MTS based on a KANBAN system. Components required for the different pumps would be ready around the assembly areas (or at least in GMH2), allowing the fulfillment of the 12-hour delivery strategy. The assembly processes are based on a MTO-strategy where actual production orders initiate the production.

Group KPIs and performance criteria

GMH2 is operating with around 30 group KPIs divided into different categories e.g. financial, customer, internal processes etc. Selected KPIs are highlighted in table 4.

KPIs	Definition	Q3 2008	Q4 2008	Q1 2009	2009 target
Pumps sold [pcs]	Number of pumps produced	41.094	39.855	32.881	N/A
Delivery reliability [%]	(total order lines - late order lines) /total order lines*100%	82	88	98	95
Order lead-time [days]	Shipment date - order creation date	13	10	5	5
Ext. rejects [pcs]	Claimed pumps /number of sold pumps	28	22	26	N/A
Warranty rates [%]	Failed products within warranty period/number of sold products	0,93	0,95	0,77	0,70
Scrap [ppm]	Total own scraped value/produced value	3.700	3.950	3.350	5.000

Table 4: Selected KPIs and results for last three Qs and the target for 2009

Delivery reliability can be pointed as the KPI which receives the most attention. GMH2 has focused intensively in 2008 to increase the delivery reliability. A trend can be spotted that the delivery reliability has increased, but it is also important to notice that the pieces of pump sold have dropped.

Concepts and programs in GMH2

Business Excellence – the EFQM Model

On strategic/conceptual level, several changes and initiatives are currently taking place in GMH2. The overall concept in GMH2 is Business Excellence (BE). The BE concept is based on a framework developed by the European Foundation for Quality Management (EFQM) and referred to as the EFQM model or Business Excellence (BE) Model [EFQM (2002]. The BE model is framework developed to guide a successful implementation of Total Quality Management (TQM) [Bou-Llusar et al 2008], hence making TQM the overall concept in GMH2.

The BE model is visualized in a framework (fig. 9) where five enablers (Leadership, People, Policy & Strategy and Processes) are an expression of how GMH2 achieve four result-categories (People results, Customer results, Society results and Key performance results). Thorough self-assessment and monitoring of progress and achieved results, learning and innovation are important parts of the model allowing GMH2 to step forward.

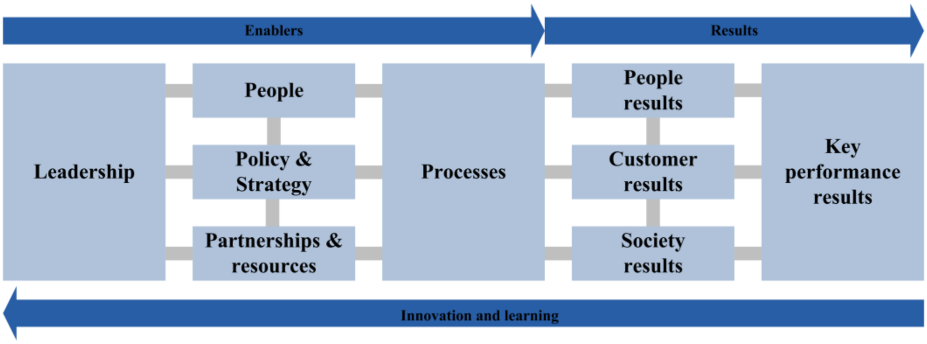


Figure 9: BE model. [EFQM]

Lean

GMH2 is currently making the first steps in the implementation of Lean Manufacturing. From Group Production, a directive has been issued that Lean Manufacturing should be the production concept in GMH2 (which in effect should support the TQM concept). Focus on customer value and reduction of waste can be classified as the core concepts in the Lean program [Rother & Shook (1999)]. GMH2 has struggled getting the Lean change-process rolling. The initiative was initiated primo 2008, however 18 months later only an isolated pilot-project (where little or no follow-up has taken place) in a single production cell has been completed. Factors such as change of Lean Coordinator, lack of results on performance measurements e.g. delivery performance, disappointment with consultant services, have caused delay in the implementation. It is not an understatement to describe the program as “back to square zero”. Fig. 10 shows the main objectives of the lean implementation, as defined in September 2008.

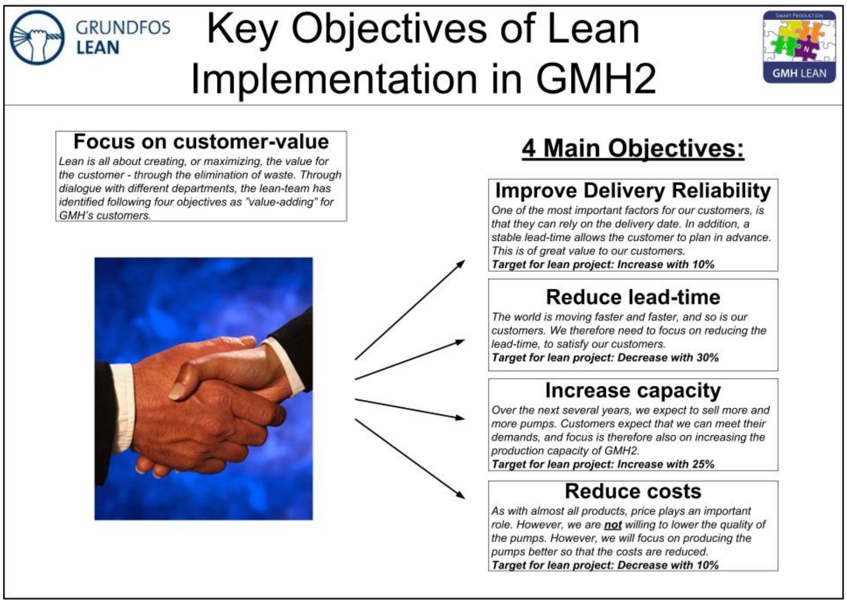


Figure 10: Key objectives for the lean program in GMH2

Six Sigma

A Six Sigma program is also running in GMH2. The program has been running for several years and several successful projects have been completed e.g. identifying of causes for missed deliveries, wrongly kitted components, etc. [MC]. Regular trainings are taking place, adding continuous growth to the "six sigma organization".

Products and their characteristics

Ranges and Applications

GMH2 assembles a part of the Grundfos' TP-series portfolio. The products being assembled are: TP100-200 (TPsmall), TP300 and TP400. In addition, NB, NK, Wastewater (WW) and DW pumps are being produced in GMH2. Fig. 11 shows the different pump ranges produced.

Figure 11: The product ranges produced in GMH2

Turnover, Quantity and MTS vs. MTO

GMH2 operates with four product categories:

- A-products: Make-To-Stock (MTS) pumps and are kept on stock in the DCs. Production of the pumps is initiated based on a replenishment-system and free capacity in the assembly cells are filled up with MTS-production orders.
- B-products: Make-To-Order (MTO) pumps and are not on stock in DCs. The pumps are a Factory-Product-Variant (FPV) meaning that they are "known to the factory". With B-products, components are kept in-house.
- C-products: MTO pumps and not on stock in DCs. The C-products are also FPV-pumps but here the components are not kept in-house.
- D-products: Engineer-To-Order (ETO) pumps where minor changes in design or material are required.

Given the ranges described in the previous section and the categories described in this, table 5 shows the yearly turnover, output and distribution of the four product categories.

Area	Yearly turnover [mill. €]	Yearly output [pcs.]	Turnover Impact	MTS A	MTO B	MTO/ETO C D	Avg. order size
TP100-200	14,6	52.282	12%	50%	33%	17%	4
TP 300	45,0	49.369	38%	45%	52%	3%	3
TP 400	2,9	514	3%	0%	61%	39%	2
NB	17,4	22.248	15%	36%	47%	17%	3
NK/TPM	8,8	8.152	7%	0%	70%	30%	2
WW	22,1	40.707	20%	80%	19%	1%	4
DW	1,0	805		0%	99%	1%	2
Spare parts	5,2		5%	N/A	N/A	N/A	N/A
GMH2 Total	117,0	173.272	100%	52%	40%	8%	3

Table 5: Turnover, output, turnover impact, distribution according to product category, avg. order size

Product variety

Given the various application purposes of the pumps, customers have various performance requirements (flow and lifting height), requirements to materials (e.g. steel, cast iron or bronze impeller), requirements to dimensions (e.g. diameter of flange), etc. By fitting different motors with different impellers, pump housings etc., the variety can be obtained. In effect this results in hundreds of variants within the different ranges. As it can be derived from table 5, 52% of these variants are MTS (A products) and 58 % are MTO/ETO (B, C and D products).

Modularization

To comply with this high variation, the pumps have a modular design, allowing different motors to be fitted with different pump housings, different impellers, etc. This results in high product variation, yet relatively low process variation.

GMH2 Production set-up

GMH2 is operating with two areas (or sub-departments) in the production. These include:

- Machining and painting
- Assembly

Machining

GMH2 has in-house machining of several components, which go into the pumps. The components are mainly made of cast-iron (few bronze and stainless steel components). In terms of volume, the Machining department's yearly production is around 285.000 components (based Q3+Q4 2007 and Q1+Q2 2008).

"Christmas-trees",

GMH2 has invented a movable rack for moving and storing the machined motor stools and pump housings weighing below 100 kg. These so-called "Christmas-trees" allow the operators to move around the components without the use of forklifts and are additionally applied as storing racks. Pic. 1 shows a Christmas-tree with painted cast iron pump housings, in addition to rows of Christmas-trees.

Picture 1: Christmas-trees with cast iron components in addition to rows of trees

Painting

In addition to machining of raw components, and estimated 99% of the machined parts are painted in the CED and/or powder painting cabins in GMH2 [LJO, GSA]. Going into the painting cabins, the components remain on the Christmas-trees, requiring minimum handling for the operators. As mentioned, the larger components cannot currently be placed on the Christmas-trees, since the trees cannot support their weight. These components are stored in pallets, handled manually and hanged on hooks in the painting cabin. Pic. 2 shows large and small components entering the painting cabin, and large components leaving the painting cabin.

Picture 2: Components leaving and entering the painting cabin

Assembly

In the assembly area, a cellular design is applied and there are six assembly cells in GMH2. Depending on the ranges produced, the cells are either built up around assembly lines, the smaller ranges e.g. TPsmall and WW, or assembly stations, e.g. TP400 and NK/TPM.

Production processes and their characteristics

High volume pump production and assembly lines

Exemplified by the TPsmall products, high volume production and assembly is taking place in GMH2. The TPsmall products are characterized by more MTS (A-products) pumps, based on the replenishment system in the DCs, with an overall average order size of 4 pcs. / order. The pumps are smaller and more standardized and the assembly process is performed on assembly lines, and operators move along the line performing the required tasks. This is also the case in the WW cell. The size of these pumps allows the assembly process to take place on assembly lines. Pic. 3 shows part of the TPsmall assembly line and SE assembly line.

Picture 3: The TPsmall and SE assembly lines

Low volume pump production and assembly stations

Exemplified by the TP400 pumps, low volume production is also taking place in GMH2. With the larger pumps, the ratio between MTS, MTO and ETO pumps tilts towards MTO and ETO pumps. The average order size is approaching one and the assembly process is performed around assembly stations, where the components are lifted and handled by large cranes. This is also the case for the TP300, NB, NK and TPM pumps.

These are the larger pumps and the assembly process is performed on assembly tables/stations. The manual assembly processes produces the pumps in a 1x1 flow. Pic. 4 shows the assembly of a TPM pump on an assembly station.

Picture 4: TPM pump on assembly station

Low-runner component machining

Cast iron components constitute nearly all of the machined components in GMH2. The equipment is automatic or semiautomatic and the operators are required to load and unload the components in addition to entering/selecting the appropriate machining program [LJO].

The FH machines (pump housing production) are extremely flexible, and they are capable of performing 1 piece (1x1) production. The constraint on the FH machines is the fixtures in which the pump housings are inserted [NRL, LJO].

The Integrex and Multiplex machines (mainly impeller, and motor stool production) are currently not as flexible as the FH-machines. Jaws hold the impellers and motor stools in place, and if a different dimensioned component needs to be machined, the jaws have to be changed.

Outsourcing vs. in-house production

The primary reason behind the in-house machining and painting of components is to maintain know-how about the machining processes internally [NHB]. Due to capacity constraints, GMH2 has outsourced the machining of high-runner components and keep the medium/low runner components in-house [NHB, LJO, ZFA].

Production planning

There are two main planning units in GMH2: the machining/painting area and the assembly area.

"KANBAN"

The primary planning tool in the machining area is a "self controlled" KANBAN system (For now the term KANBAN will be used, but it will later be discussed whether it actually is a KANBAN system). The system was intended to be controlled through the use of KANBAN cards; however GMH2 has experienced problems with cards not being sent back in the system, hampering the pull-principle. In addition, cards were lost. To overcome this obstacle, GMH2 now make use of a KANBAN-assistant, who extracts the daily consumption of KANBAN components from SAP in an excel sheet. This consumption is compared with the assigned inventory levels for the different components, and based on this comparison, production of components is initiated [AWE].

When setting up the KANBAN system, the appropriate inventory levels for KANBAN components were set for 5 days. GMH2 are still applying the KANBAN cards, but they used as pure "labels" to identify the components in the KANBAN containers (e.g. Christmas-trees or boxes).

MTO components

Not all components produced in GMH2 are running in the KANBAN system. The production of these components is initiated through "production tickets". This however, is a very limited number of components. As a generalization, it can be stated that if the component is machined in-house, it is running in the KANBAN system.

Planning in SAP

The second planning unit is the assembly areas. Here dedicated planners in the CSU department, receives customer orders, and enters the order in SAP. First of all, a material-availability check is conducted and secondly a capacity availability-check. When the appropriate date is found, the order is entered. The production will receive a production order for the given day, and the customer will receive an order confirmation with the delivery date.

The capacity-availability check is performed in SAP on the different test beds in the areas. These are in general considered the bottleneck. The planners fill up the capacity with MTO customer orders and when there is spare capacity after all MTO orders have been entered, the remaining capacity is filled up with MTS orders based on the inventory levels in the different DCs. Appendix C1 illustrates the order handling flow in GMH2.

Logistics

Incoming goods - Internal warehouse

The internal warehouse receives goods, primarily from the external warehouse (will be described in the supplier section) and a few other external suppliers. The primary functions carried out are: registration and storing of components, performing quality-checks with the Quality department, supplying the production lines, and replacing and handling of scrap. There are two docks for the trucks in the internal warehouse and 6-7 trucks are arriving at GMH2 daily. Currently 2.500 pallets are stored in the internal warehouse. Pic. 5 shows the left, center and right side of the internal warehouse.

Picture 5: The internal warehouse

The pallets are placed randomly in the free slots on the shelves and recorded in the WMS with barcodes. Few of the shelves have dedicated slots for fittings (nuts, bolts etc.) were a replenishment system (based on weight) ensures adequate levels of internally held materials.

Outgoing goods - Dispatch

When pumps have been assembled and packed, they are transported to the dispatch area. Here trucks arrive daily and ships the pumps – primarily to the DCs. The function of the DCs will be described in the customer section.

Layout

To get a visual understanding of the previous sections, fig. 12 shows the different “blocks” in GMH2.

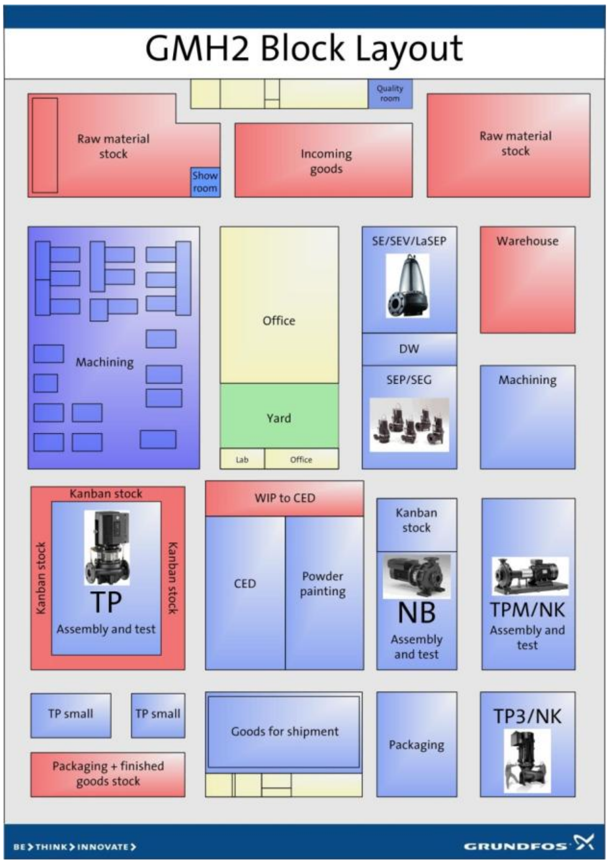


Figure 12: The "block" layout of GMH2

For further detailed information, see appendix B1.

A supply-chain perspective - Suppliers

Two suppliers will be mentioned in this section, since they are somewhat related to the problem area.

Suppliers of machining equipment

With respect to machining equipment, the primary supplier is Yamazaki Mazak (Mazak), and service agreements have been established between GMH2 and Mazak.

Third-party logistics provider

An important supplier to GMH2 is TransPoint. TransPoint functions as a third-party logistics supplier (3PLS) and is located in Tata; 12 km from GMH2. TransPoint is commonly referred to as the external warehouse. The external warehouse receives the shipments from GMH2's suppliers, with a few exceptions e.g. GMH3. The functions carried out by TransPoint are mainly storing the components and delivering them when GMH2 requests it. Currently six to seven trucks arrive at GMH2 daily. Around 17.000 pallets are kept on stock in the external warehouse [ ].

A supply-chain perspective - Customers

Distribution centers

The first step in the downstream supply chain is the Distribution Centers (DCs). GMH2 is directly supplying six DCs and 91% of the pumps leaving GMH2 are going to one of the six DCs. The DCs have two main strategic purposes [JTO]:

1. The DCs function as “hubs” in the transportation of products from the production facilities to the end-customers. GMH2 is supplying 6 distribution centers directly, however from these DCs, the pumps might be transported to other DCs e.g. in Asia or the Americas. From the DCs smaller shipments are delivered to the sales companies or end-customers.
2. The DCs keep MTS pumps on stock. These pumps are considered “shelf-products” and these can be delivered to the sales companies or end customers faster.

Given these two main purposes, the DCs can be considered a cost-center with the purpose of performing the required tasks at minimum costs.

End Customers

The pumps produced in GMH2 are primarily for the industrial market. GMH2 is operating with the following customer classification system:

1. **Domestic Building Services**: Small box products in simple applications. Typically used in private households or minor industries.
2. **Commercial Building Services**: All products sold to professional building and construction projects.
3. **OEM**: Alle sales where the customer builds the pump into another application for re-sale – system builders.
4. **IEM (industrial end-users):** Situations where the customers is a company purchasing pumps for own processes or connected applications (heating, cooling etc.).
5. **Water Supply**: Companies (private and public) where main business is within water supply.
6. **Wastewater**: Cleaning plants and other applications within drainage/removal of wastewater.

Value for the Customer

Based on an interview with a Grundfos sales representative the following factors are considered valuable for the end-customers. Three primary factors were mentioned, together with two secondary [ISZ]:

Primary factors

- Quality – the primary reason why customers choose a Grundfos pump.
- Delivery reliability – Very important since products often are inputs in larger projects.
- Stable lead times – Based on experience, the customers expects similar lead times.

Secondary factors

- Price – Plays a role however the products are intended for the high-end market.
- Short lead times – In some situations and for some products a short lead time is expected, but it is not general for the products produced in GMH2.

This information is confirmed with the information presented in [Christensen et *al* (2003)].

Overview of production system

With the information concerning suppliers, customers and the internal set-up in GMH2, fig. 13 presents an overview of the system.

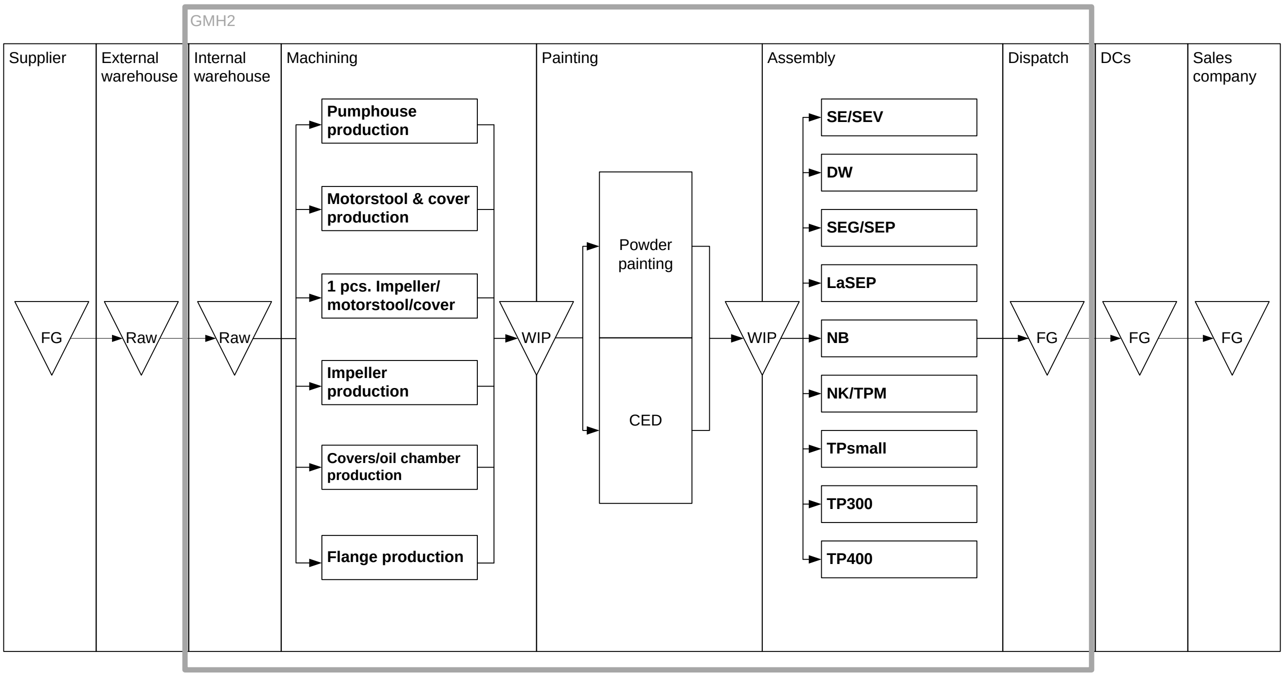


Figure 13: Overview of the production system. GMH2 is marked with in the grey square

Sum-up of Descriptive Analysis

The information provided throughout this analysis will serve as input for the following cause analysis, in addition to give the reader "a feel" for the system under investigation. The various characteristics mentioned throughout this analysis will be discussed later, in context with the information provided in the following analysis. However, as a summary a few key-issues and highlights will be mentioned.

Mix variety and flexibility

Given the different ranges and the large number of product variations within each range, it is of no question that there is a strain on GMH2. Even though the products are modular designed, there are still a large number of components (36) for e.g. pump housings for the NB pumps. GMH2 has to be flexible in the sense that they need to be able to produce a wide mix of products.

1-day delivery strategy vs. Customer value

One key-benefit is present in terms of customers. GMH2 is serving a markets with the somewhat similar characteristics and it has been possible specify a general list which identifies the *customer value*. Very noticeably, there seems to be a mismatch between the 12-hour delivery strategy and customer value. The customers are more concerned with quality, reliability and stable lead times, and not short lead times.

Independent planning and production units

The organizational diagram on fig. 1 shows a very functional divided organization. Several of the processes (e.g. processes related to production and internal warehouse), have been set up, so that communication and coordination is not required. For example, delays in the assembly area are not communicated to the internal warehouse. Another example is several of the planners in the CSU department do not have knowledge with respect to changeover times from one pump to another [GHA]. Only the team leaders in various assembly areas possess this knowledge.

The KANBAN system – focus on in-house machined components

One of the key issues is the KANBAN system. The system is highly questionable on many levels. Given the current delivery strategy, the system functions as a way to ensure all components are ready for assembly. There are some characteristics of the system which does not match a “theoretical” KANBAN system:

- The pull principle can be questioned
- No signaling is used
- There are no deliberate and continuous attempts to reduce the levels in the inventory
- It cannot be classified as self-controlled since KANBAN assistants initiate production.

MTS vs. MTO

Table 5 illustrated the four product categories in GMH2. 92% of the products are in the A and B category, implying that the variant is known to GMH2 and the component is kept on stock in GMH2. The capacity of the assembly areas are filled up with MTS products when the MTO products for a given day have been entered. It seems that the categorization of A and B products are merely used a way prioritizing the production since they currently are manufactured in the same way.

Changes in circumstances

When GMH2 was started in 2001, there was high pressure to start producing pumps as fast as possible. This is expected to influence the choice of manufacturing strategy and the general set up. Circumstances have changed. The product portfolio has expanded to several different product ranges and suddenly SQMs has become a constraint. It is very likely that the manufacturing strategy set up in 2001 does not match the circumstances of 2009.

7. Cause Analysis

The purpose of this section is to investigate the causes of the current inventory levels in GMH2. Information from the "Descriptive Analysis" will be used as primary input and investigated further.

Mix variety

The first point which will be highlighted is the variety in pumps manufactured in GMH2. In order to cope with this variety, GMH2 needs to be flexible. As mentioned in the analytical framework, flexibility often carries different meanings for different people. The meaning of flexibility referred to here, is *mix flexibility*. GMH2 needs to be able to send a wide mix of products through the production system (in a short period of time – this will be picked up in the following section). The requirement of mix flexibility puts a strain on GMH2, in terms of components. From Table 5 in the "Descriptive analysis", it can be derived that 92 % of the products are categorized as A or B products. In terms of these products, components are kept stock; hence GMH2 keeps stocks of components for 92% pumps sold. These inventories are a respond to the mix variety. The logic behind the inventories is simple: If GMH2 has the components for a wide range of products on stock; they are able to deliver a wide range of products. This leads to first root-cause:

Cause 1: The mix variety requires GMH2 to have mix flexibility. Currently GMH2 keeps stock of components for 92 % of the pumps leaving GMH2 as the flexibility measure to cope with the variety.

12-hour delivery strategy – self-inflicted variety

When looking at the inventory as a response to the mix variety, the 12-hour delivery strategy has a huge impact. The inventory is also a response to the short available production lead-time. In effect, the strategy implies that GMH2 is operating with a 12-hour production horizon. A 12-hour production lead-time for the customer orders implies that components need to be ready for assembly all the time. This, combined with the wide range and variants of products, has a huge impact on the levels of inventory. Pic. 6 shows inventory around the TP300 assembly area.

Picture 6: Inventory at TP300 assembly area

There is simply no time to have materials delivered or machined for a specific order if the order lead-time is 12 hours. The following illustrate the problem:

1. Process: Arrival of customer order
    - The CSU department receives the customer order and enters the order as production order in SAP.

2. Process: Order of components from external warehouse.
    - Based on the production orders, the procurement department sends materials orders to the external warehouse.
3. Process: Arrival, registration and quality check in the internal warehouse
    - Depending on which component, quality check can be needed. After registration of received components, the picking of components to production can begin.
4. Process: Machining of components.
    - Depending on which component the machining process can vary. For simplicity reasons, the throughput time is set as one shift.
5. Process: Assembly of pump.
    - Depending on pump range, the assembly time may vary. For simplicity reasons the assembly and packing throughput time is set for 1 shift.
6. Process: Shipment of pump.
    - When the pump is ready, it is shipped for the DC.

	Day 1	**Day 2**
Morning (6-14)	Process 1: Arrival of order Process 2: Ordering of components	Process 5: Assembly and packaging of pump
Afternoon (14-22)	Process 3: Arrival of components, Q-check and picking	Process 6: Shipment
Night (22-06)	Process 4: Machining/painting	

Table 6: Process overview with time-span

This example shows that the throughput time could be expected to be around 32 hours before pump is ready to leave GMH2 with the current processes. This does not match the 12-hour delivery strategy. The time period of process 5 and 6 show that the components must be ready for assembly if the 12-hour delivery strategy should be respected. This leads to the second cause:

Cause 2: The 12-hour delivery strategy implies that components must be ready for assembly when a customer order arrives.

Cause-effect diagram

The first cause effect diagram presented contains both of the previous described root-causes since they are found to be much related.

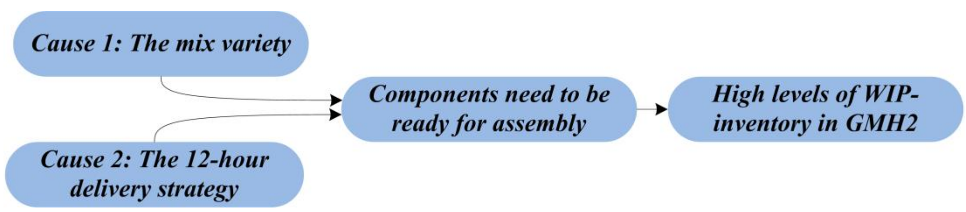


Figure 14: Cause-effect diagram 1. Root-causes: mix variety and 12-hour delivery strategy

The manufacturing principle

The manufacturing strategy in GMH2 can be classified as ATO-strategy, composed by a MTS-strategy pre-OPP and a MTO-strategy post-OPP; hence the machining of components are MTS and the assembly of the actual pumps are MTO [Olhager (2003)]. With the 12-hour delivery strategy, it can be argued that it is the only option (unless the entire production was based on MTS. However, it also entails that that the production is "out of synchronization". The machining area is focusing on filling the KANBAN inventories, while the assembly areas are focusing on production orders. This might not necessarily be bad (will be picked up in the following discussion), but it cannot avoided that inventories are required as buffers between the areas, when they are not synchronized and based on MTS-principle and MTO-principle respectively. It is not considered in the machining area on day (X) what is assembled on day (X+1). Basically all components need to be ready at the assembly area all the time. This also adds to the inventory levels in GMH2. Given the dissection of the production system, a management decision was taken to make use of a "self-controlled" planning system in the machining area, to avoid manual planning [AWE, JTO].

MTS component production through "KANBAN"

As mentioned in the sum-up of the descriptive analysis, a "KANBAN" system is applied as the primary production planning system in the machining area. When asking around in GMH2, various opinions and views of the system can be found, and it is difficult to fully explain the underlying logic behind the system. However, some key characteristics of the system can be highlighted which illustrates how the system is functioning:

- It is not clear how the KANBAN sizes are calculated exactly. Monthly consumption plays a role, but so does the size of the containers and Christmas-trees.
- Production of components is not initiated based on KANBAN cards. KANBAN cards are applied, however not as a mechanism to create pull production. The cards are used as labels for the components (e.g. attached to the Christmas-trees), so the operators can identify the components on the rack or in the containers.
- Production is initiated based on component consumption. The consumption list is extracted from SAP. Given the KANBAN sizes for the relevant components, the production of X KANBANs is initiated.
- There are no rules for the number of KANBAN cards in rotation. If extra cards are needed they are printed e.g. temporary KANBAN cards.

It can be challenged whether this qualifies as a KANBAN system. Without going into too much detail with the mechanisms of the system, it seems that the pull principle is up for discussion. In addition there is clear evidence that the components running in the system by far exceed the five-days levels that the system aims at. Pic. 7 shows pictures of KANBAN components with a significant amount of dust. The second picture shows the KANBAN racks with a significant amount of dust. This is clear evidence that the system is over-dimensioned and does not serve the "traditional" purpose of a KANBAN system: to minimize the WIP inventory [Slack (2007)].

Picture 7: Dusty kanban components and dusty kanban shelves

What is important for the problem area of this report is the fact that all the components in system are produced according to a MTS-principle with no evidence of attempts to minimize the inventory levels.

Cause 3: The current ATO-manufacturing strategy dissects the production system and adds to the inventory levels since components are produced to stock.

Cause-effect diagram

A diagram with two legs can be depicted, illustrating how the ATO-manufacturing strategy adds to the inventory level.

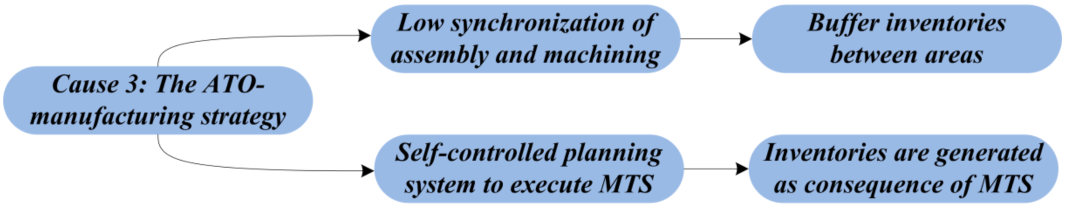


Figure 15: Cause-effect diagram 2. Root-cause: The ATO-principle

Long change-over times on machining equipment and performance measurement

Moving down on a more operational level, the change-over times is argued to influence the inventory levels in GMH2. In terms of the Integrex and Multiplex machines (motor stool, cover and impeller machining), batch production is currently appropriate since there are relatively high change-over times. The jaws, which lock the components in the lathes, need to be changed if the dimensions of the component change. This implies that it makes sense to produce the components in batches. However, the change-over times, combined with an addition factor can be expected to contribute to overproduction in the machining area.

Performance measurements

The machining area has several performance measurements. Achievement of performance measurements has a positive effect on bonus arrangements [NHB, AWE, ZBA]. Two performance measurements that are applied are:

- KANBAN fill-up rate
- Overall equipment efficiency (OEE)

The KANBAN fill-up rate is a measure for how well the machining area is capable of maintaining a constant supply of components to the assembly areas and the OEE is a measure of how efficient they utilize the machines. Underperforming in terms of the performance measurements will have a negative effect on the bonus. However, "over-performing", in terms of the fill up-up rate does not. Filling up the inventories with e.g. 120% does not have any consequences [AWE]. In addition, it can be assumed by filling up the inventories with 120% will lead to higher OEE measures, since larger batches are produced. This is very like to cause overproduction and increasing the inventory levels. In addition, it can be expected that the OEE performance measurement in itself leads to increased inventories. By e.g. batching KANBAN cards (producing larger batches) the machining area can reach a higher OEE number, since less change-over are required.

Cause 4: The change-over times (especially combined with the current performance measurements) makes batch production efficient and overproduction likely

Cause-effect diagram

A fairly simple cause-effect diagram illustrates the causal relationship

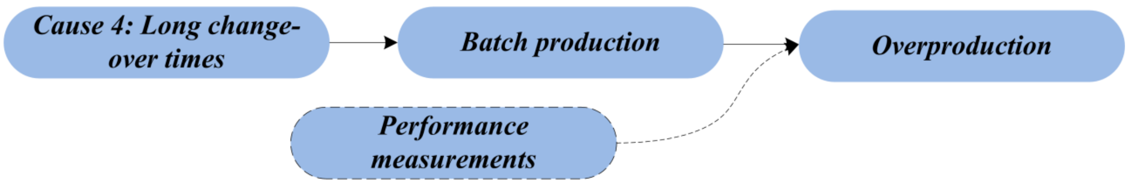


Figure 16: Cause-effect diagram 3. Root-cause: Long change-over times

Unreliable processes

The inventory levels in GMH2 for in-housed machined components have been set for five days. These levels were created in 2001 and based on the following logic:

	Day 1	Day 2	Day 3	Day 4	Day 5
Process description	Ordering of materials from external warehouse	Arrival of materials, Q-check and picking	Machining of components	Painting of components	Arrival of components to assembly lines

Table 7: The logic behind the inventory levels in 2001

In the different process steps, there are certain deadlines (e.g. ordering of materials should be at the external warehouse at 10:00 for the shipment at 14:00). The process described in table 7 allows for several delays throughout the chain; an appropriate logic when starting a production system. In addition safety margins are included to account for machine breakdowns, supplier delays or other unanticipated delay. The five day inventory levels can be classified as safety or buffer inventory, since the process steps can be completed in less than two days. A more realistic "process-schedule" has already been described previously in this chapter, but for overview purposes it restated here.

	Day 1	Day 2
Morning (6-14)	Process 1: Arrival of order Process 2: Ordering of components	Process 5: Assembly and packaging of pump
Afternoon (14-22)	Process 3: Arrival of components, Q-check and picking	Process 6: Shipment
Night (22-06)	Process 4: Machining/painting	

Table 8: Process overview with time-span

When comparing the two tables, it can be deducted that with five days inventory levels, the inventory (over) compensates for any unanticipated delays and breakdowns, but it cannot be disputed that it adds to the current inventory levels

Cause 5: Unreliable processes implies that safety and buffer inventories are set up to compensate for delays, breakdowns or other unanticipated factors causing delays

Cause-effect diagram

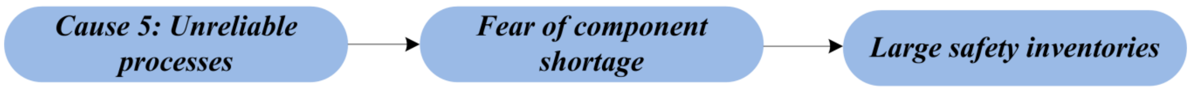


Figure 17: Cause-effect diagram 4. Root-cause: Unreliable processes

Complex material flows

The focus area for the material flows is with respect to incoming goods in GMH2; hence the flows around the external warehouse, internal warehouse and the production. Appendix D1 shows the material and information flows, as mapped during a kaizen event facilitated by the author of this report in March 2009.

Mapping the flows

The mapping shows several (six) material flows for incoming goods. The flows are similar, yet still several flows increases the complexity of the processes undertaken. Some components are stored internally, some externally. Certain components are required to undergo quality-checks. In addition, some components cannot be removed from the original packaging in the external warehouse due to lack of tools, and exceed components are therefore brought to GMH2. In some cases the exceed components are stored in GMH2, in other cases they are brought back to the external warehouse. The investigation of the material flows showed that pallets may be touched up to 13 times from arriving from the supplier, delivered to the production line and stored in the external warehouse again. From a lean point-of-view this can be classified as extensive waste [Rother & Shook (1999)].

Disorder leads to disorder

With respect to the problem area under investigation in this report, the extensive handling and extensive flows hamper the overview and possibility to organize in an efficient manner. The phrase “disorder generates disorder” describes the phenomenon. Examples in GMH2 were discovered from waste-walk during the kaizen event: several half-used pallets with same components, bulk storage of components, problematic materials waiting for decision, scrap components waiting to be handled, pallets not touched for years are present in the internal warehouse. It becomes difficult to discover problems when they are hiding in a complex, unorganized mess.

Cause 6: Complex materials flows hampers the transparency and overview of the components stored in the internal warehouse.

Cause-effect diagram

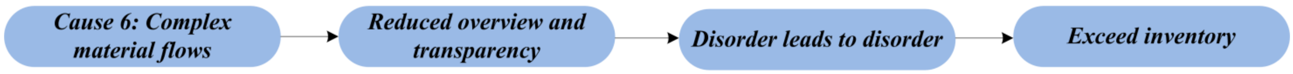


Figure 18: Cause-effect diagram 5. Root-cause: Complex material flows

The purpose of the internal warehouse

In the sum-up of the descriptive analysis, fig. 13 showed the production set up in GMH2. The same figure is presented as fig. 19, with a marked area.

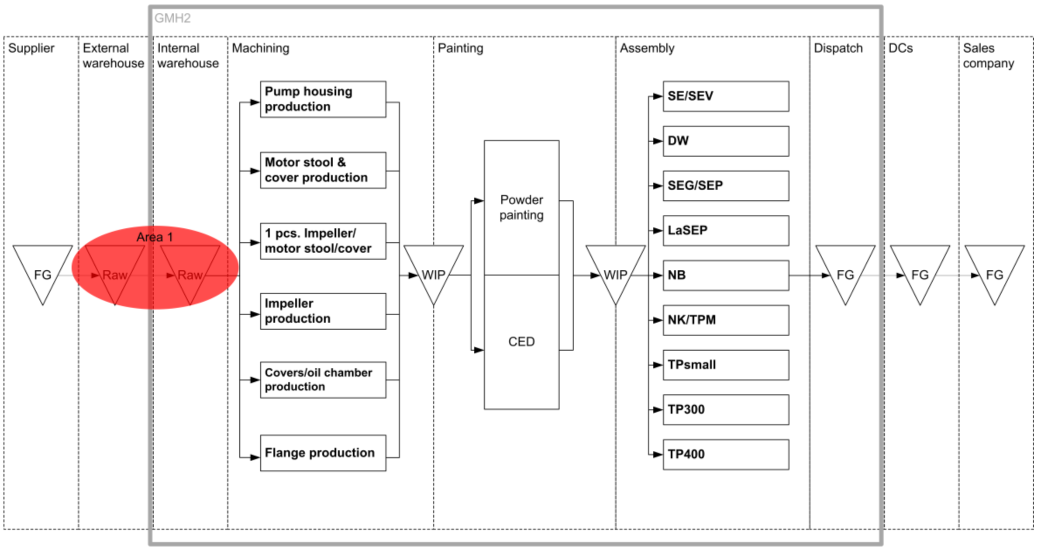


Figure 19: The production system

With focus on area 1, it strikes out that GMH2 is carrying a double raw-material inventory. The question in focus here is: what is the purpose of the internal warehouse? Logically, it can be expected the internal warehouse should account for time gab between ordering and receiving components from the external warehouse. For simplicity reasons, it is assumed that time gab, with the current processes, between the external and internal warehouse is 24 hours; hence components for 24 hours should be kept on stock. This is not the case. According to the logistics manager, a rough estimate is that around 400 pallets of raw components are consumed within 24-hour production period. Currently, 2500 pallets are on stock in the internal warehouse. The reason is that the purpose of the internal warehouse is not well defined. This was confirmed during the previous mentioned kaizen event. Since the space and shelves are there, they are used for bulk storage.

Relation to previous root-cause

It can be argued that the bulk storage in the internal warehouse is also partly due to unreliable processes. If there are discontinuities in the delivery processes, the bulk storage serves as a buffer. This however, is found more to be an excuse than reality. Going through the reasons for delays in production, the logistic manager pointed out in the database that only one out of several hundreds was due to wrong deliveries [AWE].

Cause 7: The purpose of the internal warehouse has not been defined and it is currently used for bulk storage.

Inadequate BOMs

However, a valid reason discovered for the internal bulk storage is the BOMs. Several of them are flawed and have not been corrected [lotus notes database]. With inaccurate information on the BOMs, the wrong components are delivered to the assembly areas. Here the internal warehouse functions as a safety net. When the operators discover the wrong components, they have the opportunity to retrieve it faster from the internal warehouse compared to the external warehouse.

Cause 8: Inaccurate BOMs cause the internal warehouse to be used for bulk storage since the correct components can thereby can be retrieved relatively fast .

Cause-effect diagram

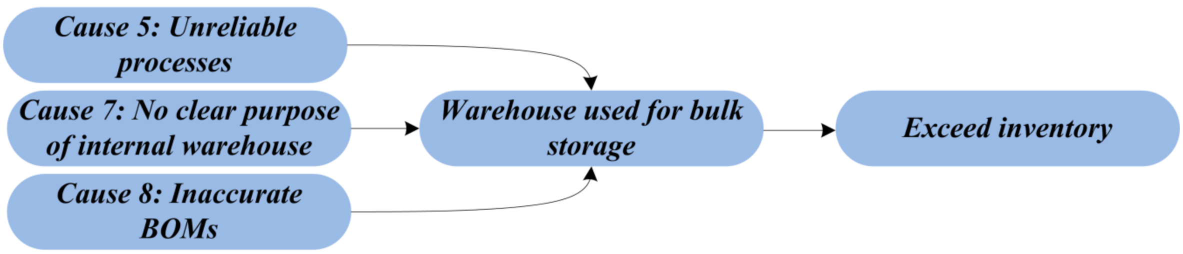


Figure 20: Cause-effect diagram 6. Root-causes; Unreliable processes, No clear purpose of internal warehouse and inadequate BOMs

Sum up

Eight root-causes have been identified as the major drivers for the current inventory levels in GMH2. These root causes are summed in the fishbone diagram in fig. 21

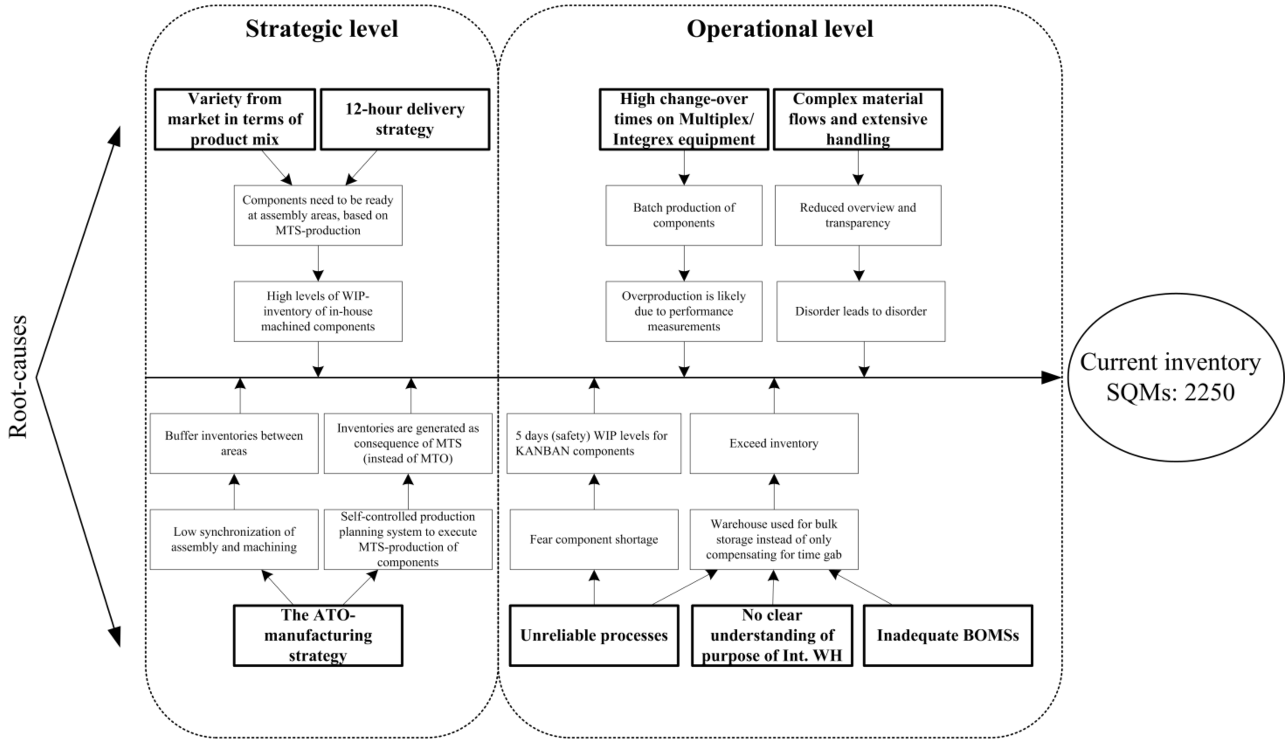


Figure 21: Fishbone-diagram which sums up the causes of the current inventory levels in GMH2

In the following discussion, these will treated further in context with each other. The purpose of the discussion will be to illuminate characteristics of the causes in order to develop solution suggestions which yield prime results for GMH2.

8. Discussion of Diagnostic

The cause-analysis successfully identified eight root-causes of the inventory in GMH2. In this discussion, the root-causes will be discussed from several different perspectives and in context with each other.

Root-causes as contaminators

One important aspect which needs to be discussed is "the hierarchy" of the root-causes in the sense that they span on different levels in GMH2. Fig. 22 shows the eight root-causes divided into a two-leveled hierarchy. It can be argued that the root-causes on the higher levels affect or contribute to the root-causes on the lower levels.

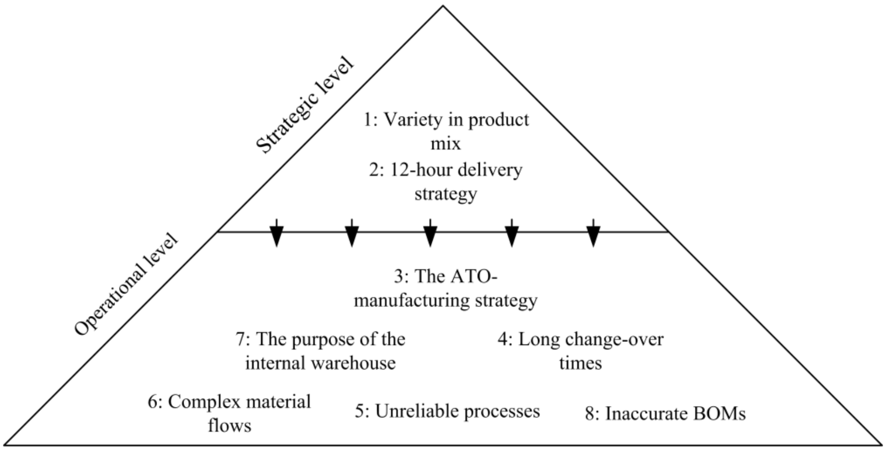


Figure 22: The hierarchy of root-causes

To some extend that implies that root-causes on the lower levels perhaps are effects of the root-causes on the higher levels. There is certainly a lot of truth to that. However, the root-causes have been highlighted, since it can also be argued that if they are targeted isolated, it will also have a decreasing effect on the inventory in GMH2.

The 12-hour delivery strategy and ATO-manufacturing

A key discovery in the diagnostic is the impact of the 12-hour delivery strategy. With a 12-hour order lead-time, GMH2 is basically forced to manufacture based on an ATO-principle with the OPP positioned as late in the internal supply chain as possible. The current system supports the strategy, but as mentioned in the cause analysis: what does the strategy reflect?

It can further be argued that the ATO-manufacturing principle has an indirect impact on the high change-over times. The MTS-production of components (based on the KANBAN system) somewhat moves focus away from the change-over times of the equipment.

The point is here, that root-causes located on a strategic level leads to root-causes on an operational level. Root-causes place lower in the hierarchy can be expected to be an indirect consequence of a root-cause placed higher in the system.

Inventory as a response to/consequence of problem phenomena

It is important to understand that (the majority of) the inventory GMH2 is there as a response (antidote) for some sort of problem phenomena. A way to depict the point is the well known pictures from the "lean picture gallery", where inventory is believed to "cover up" some problems in the organization ("cover up" and response might not always be the same). Fig. 23 such pictures.

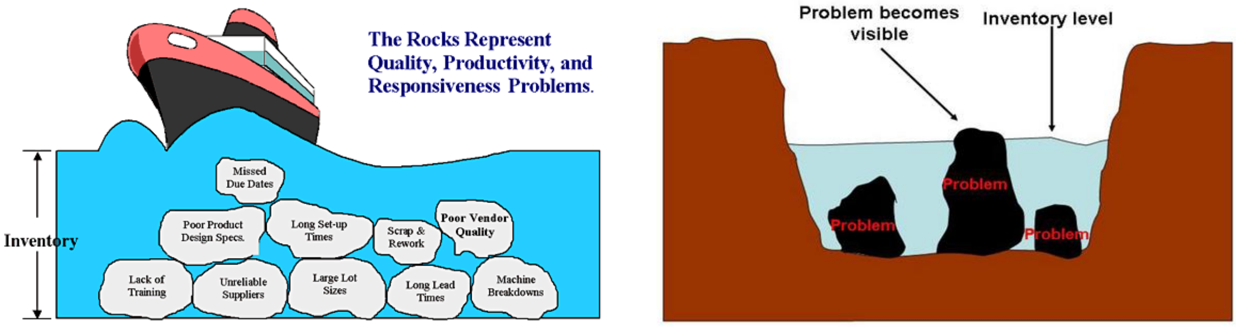


Figure 23: Inventory as cover-up from the lean picture gallery

Problem phenomenon 1: Variety and uncertainty

With eleven different ranges and numerous (hundreds of) variations within each, GMH2's production system is exposed to mix variety. It is very unlikely that the customer orders for day X are similar to the customer orders for day Y. The mix is constantly changing which impose a challenge for GMH2. Currently, having components for 92% of the pumps on stock allow GMH2 to deal with this variety.

An important note

An interesting discussion would be to what extend the many variants are actually required and also whether the modular product design could be improved? However, as mentioned in the "Study Design" this is outside the scope of this study. It is expected that GMH2 is subjected to the decisions made on Group level and these considerations are outside the decision realm of GMH2.

Adding uncertainty

When discussing the issue of mix variety, the 12-delivery strategy must be considered as well. If GMH2 had months to produce a given mix, component inventory would not be required inside the production facility. The fact that a pump must leave GMH2 within 12 hours upon arrival of the order suddenly enhances the problem. Not only is GMH2 required to produce a wide product mix; they are also required to do it within 12 hours. [Slack (2005a)] mention *delivery flexibility* "as the ability to move production orders back and forth", which is very similar to what GMH2 is required to do. As showed in the cause analysis, pre-fabricated components are required around the assembly areas to cope with this uncertainty.

Self-inflicted variety

The big question mark here, is why a12-hour delivery strategy pursued? From a customer point-of-view, short delivery times are not important. Focus is on delivery reliability. In addition, from a Group perspective the target for the order lead-time in GMH2 for 2009 has been set for five days. On top of that, GMH2 is actually not following the 12-hour strategy. The average lead-time is five days and during the last year, it has not been below. The only way in which the strategy comes to show is in terms of inventory.

When addressing some of the managers with this issue, the primary argument was that even though the strategy is not being followed, GMH2 should still be able to do so if the customers require it. It has not been possible to dig out any data as to how many orders are actually produced as "rush orders" and delivered within 12 hours, but there seems to be a general consensus in GMH2 that it is very few in a year [AWE, NHB, and GHA]. There seems to be large degree of inconsistency in the way GMH2 has chosen to set up the production system with respect to delivery time and what both customers and the Group expect. It is very likely, that the circumstances in 2001 called for a 12-hour order lead-time simply because there was a pressure to start producing pumps fast. However, it seems that the circumstances in 2009 allow GMH2 to extend the production to around five days and actually get rid of large amount of variety and uncertainty.

Process variety and uncertainty

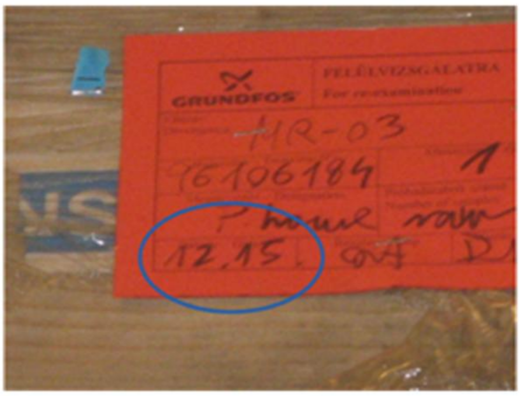
Another type of uncertainty and variety that GMH2 is exposed to is in terms of their processes. Fear of component shortage due to delays or breakdowns was found to be root-causes. GMH2 does not have complete confidence and trust in their material delivery- and machining processes. One can argue that if a process fails, it varies. By setting up these safety and buffer inventories, GMH2 obtains *process* and *supply flexibility*. They are still capable of producing pumps if one or more steps in the internal supply chain processes fail. The inaccuracy of the BOMs can also be argued to bring uncertainty and variety into the production context of GMH2.

Sum up on variety

It can be argued that the inventory in GMH2 is partly functioning as a *flexibility-measure* to cope with the mix variety and uncertainty that GMH2 is exposed to. In addition, it is argued that due to some strategic decisions, GMH2 actually enhances the variety and uncertainty under which they have to operate. This is also the case with the BOMs, just on an operational level. This is a very unfortunate situation. GMH2 should strive to minimize the uncertainty instead of increasing it. It cannot be at the expense of the customers, but implementing a strategy which virtually makes planning and synchronized production impossible, without any pressure or desire from important stakeholders should be reconsidered. GMH2 is currently forcing them self to be able to "produce everything all the time". Under some market conditions (e.g. hyper competitive markets) this could be required however this is not the case for GMH2.

Problem phenomenon 2: Complexity

Compared to variety and uncertainty, the problem with complexity is actually not something which is being solved or matched with inventory. Complexity is actually a "driver" for the inventory. With enhanced complexity overview and transparency is hampered. An illustration of the problem can be made with a presentation of a few pictures. Currently, in the internal warehouse, several shelves are filled with pallets containing scrap components (indicated by the red label). Pic. 8 shows the shelves



Picture 8: Shelves with scrap components in the internal warehouse. Due to the complexity some pallets stand untouched for months

These shelves are several meters high and identifying the labels is basically impossible. An interesting observation was made when the author of this report zoomed in on some of the pallets on the upper shelves and took a picture. Notice the date on the label marked with the blue circle. This photo was shot in April 2009. With pallets being stored in GMH2 for various purposes, due to different arrangements with suppliers etc., these situations are bound to occur. It is impossible to maintain overview.

The drivers of complexity
Given the rapid growth of GMH2 over the past eight years, it can be argued that increased complexity is almost a natural consequence. GMH2 has expanded so rapidly that it almost seems unavoidable. With continuous introduction of new pump ranges and variants and a continuous increasing organization, little time has been left to do self examination – as mentioned in the introduction.

Making sense of a complicated situation
The key finding in the diagnostic is, that there are evidence that GMH2 is actually "over compensating" in terms of flexibility, which in effect leads to inefficiency [Boer, lecture AAU]. In this case the inefficiency comes to show in extensive inventories, primarily built up as a response to the variety and uncertainty GMH2 is subjected. However, some of the variety and uncertainty is self-inflicted. [Slack (2007)] stress that the competitive factors under which an organization operates should be reflected in the performance objectives. GMH2 has put itself in a situation where it strives to accomplish everything instead of striving to do what required.

An example of inconsistency
There is strong evidence that there exists inconsistency, especially between the strategic decisions related to the manufacturing set up and the market/stakeholder requirements. It is noticeably that the MTS and MTO pumps are produced by the same manufacturing principle. However, it seems to be a natural consequence of the 12-hour delivery strategy. GMH2 shuts down several possibilities by having this strategy in place.

Inventory as flexibility-mean
It is argued that GMH2 applies inventory as a way of coping with the uncertainty they are exposed, but also the uncertainty they inflict on themselves. However, the consequence of applying inventory as a flexibility-mean clearly comes to show in GMH2. The material and information flows in, out and inside of the factory have now become so complex that GMH2 is experiencing difficulties expanding in the long-term. [da Silveira (2005)] mentions this. When an organization applies inventory for flexibility reasons in the short-term, they cripple themselves in the long-term due to the increased complexity. Some fundamental changes in the strategies and principles are required if GMH2 wants to obtain a significantly higher production volume within the existing facility.

9. Conclusion diagnostic

The sole purpose of this conclusion is to sum up on the first part of the report by answering the four working questions presented in "Study Objectives"

What are the SQMs occupied by inventory?

The area utilization showed that currently 2250 SQMs is occupied by inventory in GMH2. This accounts for 19% of the total area available for production. In addition, walking space is required in order to get access to the inventory. These as well, could be expected to be made available for production if the inventory is removed.

How is the production system in GMH2 set up?

The system consists mainly of a machining and an assembly area. Mainly cast iron components are machined, and one of eleven pump ranges is assembled in the assembly areas. There are several variants within each range.

The production system is set up according to an ATO-principle. The system is dimensioned so that it theoretically should be able to complete a customer order of an A or a B product within 12 hours. The A and B products accounts for 92% of the pumps sold.

The machining of components is based on a MTS-principle. The machining area is planned and controlled by a system which is labeled "the KANBAN system". It would be incorrect to define the system as working according to the traditional KANBAN-principles. The in-house machining is mainly low and medium runner components. The high-runners are outsourced.

There is an external and an internal warehouse attached to the production system. The suppliers are expected to deliver to the external warehouse but this is not always the case. Components are being stored in the internal warehouse for various reasons, and there seems to be some confusion with respect to the purpose of the internal warehouse. GMH2 delivers to the DCs which distributes the pumps to the end customers. In addition the DCs keep stock of the MTS pumps.

The overall concept in the organization is TQM which comes to show in the Business Excellence initiatives currently running in the organization.

What are the root-causes for the current inventory levels in GMH2?

Eight root-causes are identified as causes for the current inventory levels in GMH2. These are both strategic and operational causes:

1. The variety in product mix (strategic)
2. The 12-hour delivery strategy (strategic)
3. The ATO-manufacturing principle (strategic)
4. The long change-over times on the integrex and multiplex (operational)
5. Unreliable processes (operational)
6. Complex material flows leading to reduced overview (operational)
7. Undefined purpose of internal warehouse (operational/strategic)
8. Inaccurate BOMs (operational)

There is interdependency between the root-causes in the sense that the strategic root-causes "contaminate" GMH2 and have an effect on the creation of the operational root-causes.

What purpose does the inventory in GMH2 serve?

The first category of why the inventory is present is to provide flexibility. The inventory is present in GMH2 as a flexibility-measure against the imposed and self-inflicted variety under which GMH2 operates. The inventory allows GMH2 to have mix flexibility with the 12-hour delivery strategy. Furthermore the inventory allows GMH2 to run a smooth production even though some processes (machining and delivery) are unreliable. This is the same case with the BOMs. With inventory present in GMH2, the errors in the BOMs do not affect the production flow. In addition, the inventory serves as a buffer, primarily between the MTS production in the machining area and the MTO production in the assembly areas.

The second category of why the inventory is present is because of inventory itself. The complexity that the inventory brings, allows additional inventory to build up because the employees in GMH2 loose overview and transparency. The author of this report is not aware of whether there is a proverb saying *"inventory breeds inventory"*, but there certainly should be one.

10. Establishment of "Best Practice"

The following chapter serves to describe the outcome of the literary study performed to find the solutions for the root-causes. It will provide theoretical insight for the terms and concepts applied throughout the second part of the study.

It has been concluded that the inventory in GMH2 is primarily there for two reasons:

1. As a way to ensure mix and (to some extend delivery) flexibility: As a response to market variety and uncertainty
2. As a result of increased complexity: Partly due internal self imposed variety, but also as self re-enforcing phenomenon.

Previously *flexibility* was argued to be the antidote for variety and uncertainty. However, it has not been established how an organization becomes flexible. Being a relative new topic in operations management, most literature on flexibility either defines the concept (taxonomies) or focuses on the effects of flexibility on performance [da Silveira (2005)]. A question remains though: How is flexibility built into the manufacturing system? GMH2 has chosen inventory as their "flexibility-weapon", but are there other ways?

The rigid flexibility model

A literary study has shed light on two important concepts to obtain flexibility: The rigid flexibility model and the strategic positioning of the OPP.

Based on simplicity and discipline

[Collins & Schmenner (1993)] propose what they term the "rigid flexibility model". The model distinguishes itself, in the way that it does not propose building capacity or inventory buffers as the means to achieve flexibility [da Silveira (2005)]. Intuitively, one would expect that a loosely knit organization with an "ad hoc" mindset would be flexible. [Collins & Schmenner (1993)] argue the opposite. *"…if the requirement is flexibility, then an atmosphere of permissiveness cannot be tolerated."* The authors argue that if flexibility is the goal, the organization must be based on simple, foolproof, consistent procedures and processes which are carried out in a disciplined and dictated fashion [ibid].

An analogy

The authors make use of an analogy to explain the paradox that if flexibility is to be obtained, simplicity and discipline must be enforced. The analogy is the gymnast. In order to gain flexibility, the gymnast has to maintain a strict regimen of training. It is the same with organizations.

Simplicity

Simplicity is about streamlining organizations information and material processes:

- Streamlining of strategies and markets
- Streamlining of material and information flows
- Reduction in operations complexity
- Inventory reduction
- Modular design
- Standard footprints
- Elimination of waste

By setting up simple systems and processes these can easily adapt to the requirements [Collins et *al* (1998)]. The flows are standardized throughout the organization and overview and visibility is obtained. It can be argued that the organization is more generic from applying simple best practices.

Discipline
Discipline refers to the reliability and organizing in materials and information processing:

- Preventive maintenance
- House keeping
- Standardized procedures
- Data maintenance in SAP
- Continuous improvement
- Leveled production plans
- Sharing of information and data

One thing is setting up appropriate processes and procedures. Another thing is following them. Discipline is not about stiffening procedures, but rather about setting up/promote best practices which allows the organization to be flexible [Collins et *al* (1998)]. Here management plays a key role in motivating guiding and instructing. Fig. 24 shows the "rigid flexibility model"

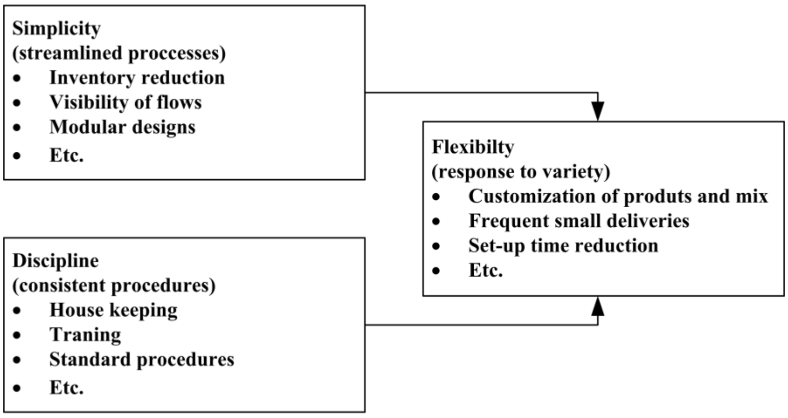


Figure 24: The rigid flexibility model. Source: [da Silveira (2005)]

Empirical examination of the rigid flexibility model
Two studies were found, both performing an empirical examination of the model [Collins et *al* (1998), da Silveira (2003)]. Both studies made use of the data from databases gathering data from manufacturing companies in different countries and industries ("Made in Europe" and "Made in Switzerland" combined and "The International Manufacturing Strategy Survey" (IMSS), respectively). Both studies tested hypotheses concerning the effect of simplicity and discipline on organization flexibility [ibid]. Both studies concluded that simplicity and discipline have a positive effect on flexibility as defined by [Slack (1987)].

Based on the rationale behind the model and the empirical examinations of the model, it may be assumed that implementing the rigid flexibility model in GMH2 would provide GMH2 with flexibility and allow to reduction of inventories.

The strategic positioning of the order-penetration-point

Another body of literature is found to have an impact on mix flexibility and reduction of inventory. [Olhager (2003)] argues that from a strategic point-of-view, the positioning of the OPP is a way of achieving flexibility in response to demand variety.

Definition of the OPP

Traditionally the OPP is defined as the point in the manufacturing value chain for a product, where the product is linked to a specific customer order [ibid]. The OPP is divides the manufacturing activities that are forecast-driven (upstream OPP) and those that are customer-order-driven (downstream OPP). Fig. 25 shows four different product delivery strategies, where the dotted lines indicate a forecast-driven MTS policy and the full lines indicates an order-driven MTO policy. The blue square defines the traditionally manufacturing processes.

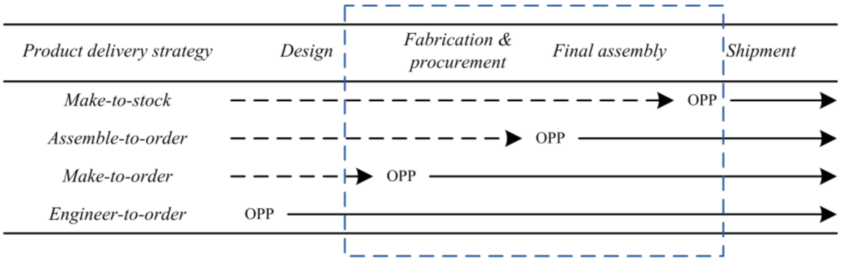


Figure 25: Four different product delivery strategies. Source: [Olhager (2003)]

It can be derived from the figure that an ATO strategy is actually a combination of MTS policy upstream-OPP and MTO policy downstream-OPP [ibid].

Factors affecting the OPP

[Ibid] argues that there are number of factors which affect the positioning of the OPP. Table 9 sums them up.

Market-related factors	
Delivery lead-time	Restricts how far back the OPP can be positioned
Product demand volatility	Indicators of whether products should be MTS or MTO
Product volume	Related to volatility. High volume prod. can be expected to have low volatility
Product range and cust. requirement	Broad product range and wide customization make MTS virtually impossible
Customer order size and freq.	Indicators of volume and repetitive nature of demand
Seasonal demand	May be uneconomical to respond to all demands when they occur
Product-related factors	
Modular design	Typically related to ATO product delivery strategies
Customization opportunities	Restricts how far back the OPP can be positioned
Material profile	The number of items at the various levels of structure. Letters A, V, T and X
Product structure	The breadth and depth indicates product complexity
Production-related factors	
Production lead time	Plays a role with respect to the delivery lead time demands from market
Planning points	Restricts the number of potential OPPs
Flexibility of processes	E.g. short change-over times are a prerequisite for MTO
Bottleneck	Depending on perspective the bottleneck should considered with respect to OPP

Table 9: Sum-up of factors which affect the OPP. Source: [ibid]

[Ibid] propose a conceptual model for understanding how the factors that potentially affect the positioning of the OPP are interrelated. Fig. 26 shows the model.

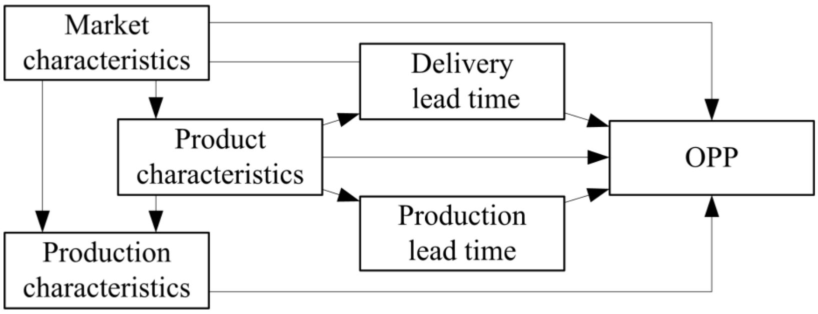


Figure 26 Conceptual model for factors affecting the OPP. Source: [ibid]

Manufacturing strategy and the OPP

The manufacturing strategy is strongly related to the marketing and product strategy [ibid]. There is a need to differentiate the manufacturing strategy according to pre and post OPP operations. Table 11 illustrates some attributes of the manufacturing strategy for pre-OPP and post-OPP operations.

Attributes of manufacturing strategy	*Pre-OPP operations*	*Post-OPP operations*
Markets and products		
Product type	Standard, commodities	Special
Product range	Predetermined, narrow	Wide
Demand	High volume, predicable	Low volume, volatile
Order winners	Price	Design, flexibility, delivery speed
Market qualifiers	Design, quality, on-time delivery	Price, quality, on-time delivery
Production (decision categories)		
Process	Line, high-volume batch	Job shop, low-volume batch
Capacity	Lag/track	Lead/track
Facilities	Product focus	Process focus
Quality	Process quality focus	Product quality focus
Organization	Centralized	Decentralized
Production planning and control	Pull-type execution	Push-type execution
Performance measurements	Cost productivity	Flexibility, lead times

Table 10: Attributes of manufacturing strategy and the relation to pre and post OPP operations. Source: [ibid]

Positioning the OPP

Given this differentiated view on the manufacturing strategy related to pre and post OPP operations, [ibid] presents the rationale for adjusting the placement of the OPP. There are basically two driving forces for moving the OPP forward:

1. Reduce the delivery lead-time to the customers
2. Increase the manufacturing efficiency.

In addition, the driving forces for moving the OPP backwards is to increase the knowledge of the contents of the customer orders at the time of the production, i.e. allowing a higher degree of customization and to reduce the WIP inventories. Table 12 and 13 shows the competitive advantages addressed by shifting the OPP back and forth.

Rationale for moving the OPP forward:

Competitive advantages addressed	Reasons for forward shifting	Negative effects
Delivery speed Delivery reliability Price	Reduce the customer lead time Process optimization (improved efficiency)	Rely on forecasts Reduce product customization (to maintain WIP and inventory levels) Increase the WIP due to more items being forecast driven

Table 11: Rationale for moving OPP forward. Source: [ibid]

Rationale for moving the OPP backwards:

Competitive advantages addressed	Reasons for forward shifting	Negative effects
Product range Product mix flexibility Quality	Increasing the degree of product customization Reduce the reliance on forecasts Reduce or eliminate WIP buffers Reduce the risk of obsolescence of inventories	Longer delivery lead times Can affect delivery reliability Reduced manufacturing efficiency

Table 12: Rationale for moving OPP backwards. Source: [ibid]

If looking at table 13, the problem area of this report seems to match the rationale of moving the OPP backwards, at least for some of the products produced in GMH2.

It should be clear that the theories and ideas presented throughout this chapter can be view as the theoretical solution to the root-causes and can be classified as best practice. The report will now move into the solution development phase where the concepts and ideas presented here are applied in the context of GMH2.

11. Solution suggestions

This chapter proposes the solution suggestions of this study. Based on the findings in the diagnostic and the establishment of "Best practice" in the previous chapter, the concepts will be applied in the context of GMH2.

The suggestions provided throughout this chapter will be initiated with some strategic suggestions. The goal is to illuminate how the different strategies should be formulated to ensure consistency from various perspectives. The second range of suggestions will be more on an operational level. The goal is here to support the strategic suggestions. The starting point for these solution suggestions may seem a bit illogical; however the information is required in order to support the addition suggestions.

Clear definition of what types of components are produced in-house: MTO components

Recall from the descriptive analysis, that GMH2 outsources the machining of high-runner components. This is done due to some cost-considerations. It is simply cheaper to have the components machined with specialized companies [NHB, JTO]. GMH2 then keep the machining of low and medium runners in-house. The descriptive analysis also showed close to a 50/50 distribution of the MTS products (A products) vs. MTO and ETO products (B, C and D products). A rough estimation is that the components machined from suppliers accounts for roughly 50% of the total number of used components. These components are expected to standard components (high runners), primarily for the MTS pumps, or at least they should be.

What should be changed?

Primarily from a cost perspective, it is argued that the machining of components going into the MTS pumps should be outsourced to suppliers. It has to be assumed that the standard components are the high-runners and customized components are the low/medium runners. There is evidence pointing towards that this is more or less taking place, but the distinction is made more towards high-runners vs. low-runners. The distinction should be towards components for MTS pumps vs. components for MTO pumps.

What this does, it that it solely "directs" the machining area as an internal supplier for the MTO pumps. As it will be showed later, this has some huge benefits since there are different market requirements for the MTS and MTO components.

Focus on capacity

It can be expected that the capacity of the machining area does not "match" the MTO vs. MTS ratio 100%. Two scenarios are possible: Either GMH2 has over-capacity in the machining area or they have under-capacity. What should be done is a selection of either a group of MTS components or a group of MTO components with which GMH2 can even out the capacity in the machining area. Fig 27 illustrates the point.

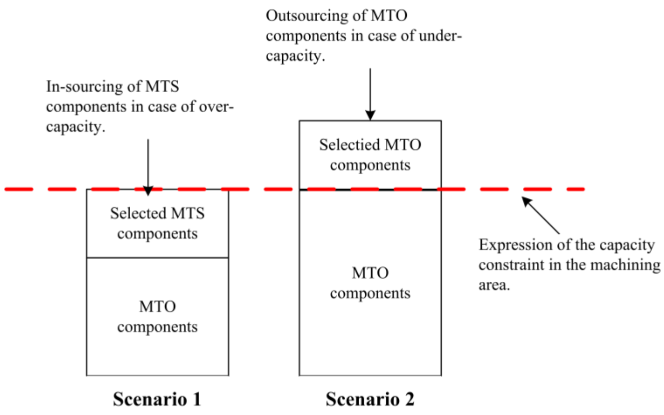


Figure 27: In case of over or under-capacity, MTO or MTS components are out or in-sourced

The line of reasoning is very similar to what GMH2 is currently doing in assembly areas. The planners in the CSU department add MTS-production orders for a given day, when the MTO-production orders have been entered, in order to utilize the capacity. The only difference is, that in this case, the opposite scenario is also present.

What are the benefits?
First of all it can be argued from a cost-perspective that the standard components are cheaper to outsource. Secondly, from a flexibility point-of-view, it is now clear that there is one set of process steps for the MTS pumps (delivery of components and assembly of components) and one set of process steps for the MTO pumps (delivery of components, machining of components and assembly of components); hence simplicity. As it will be showed later, this difference is important, especially when focusing on the 12-hour delivery strategy.

Suggestion 1: Simplify the in-house machining to machining of MTO-components.

A differentiate view on MTS and MTO products in terms of delivery strategy

The second suggestion is a differentiated view on the market requirements for MTS and MTO products. The MTS pumps are on stock in the DCs, and the end-customers expects to be able to pick these products off the shelves. In terms of the MTO pumps, the customers have focus on quality, functionality and delivery reliability. They expect merely expect “reasonable” and somewhat stable lead-times. This is not reflected in GMH2’s delivery strategy where the A and B products should be able to be shipped within 12 hours.

The logical point of view
The fundamental idea is, that if a product is a MTS product, aka a standard product, is should be manufacturing and delivered based on a MTS-principle. If a product is MTO product, aka a customized product, is should be manufactured and delivered based on a MTO principle [Boer].

The problem: “Everything ready all the time”
The problem with the 12-hour delivery strategy for both the A and B products is that it forces GMH2 to have components for 92% (A and B products) of the pump ranges ready for assembly. Basically, everything (92%) needs to be ready for assembly all the time. This causes a problem, especially with the MTO products, since the machining processes cannot be completed within the short time frame.

What should be changed?

GMH2 should change the delivery strategy accordingly to the product categories. The DCs keep inventory of the MTS pumps. In order to maintain the inventory levels at the DCs, the 12-hour delivery strategy is found to be suitable. If the delivery strategy is extended, the inventory levels at the DCs must be adjusted accordingly, not to avoid stock-outs. Since the customers expects to pick the products of the shelves, it makes sense to have the OPP positioned as far back in the supply chain as possible (see "Establishment of Best Practice).

With respect to the MTO products, the 12-hour delivery strategy should be changed. First of all, from a market perspective the customer accepts a longer delivery-lead time when the products are MTO. Secondly, from an internal perspective GMH2 is machining the components for the MTO pumps. If the delivery time is 12 hours, GMH2 is forced to follow a MTS principle for the machining area. If the delivery time is lengthened, GMH2 will open up the possibilities for machining based on a MTO principle. As mentioned in the discussion, this 12-hour delivery strategy for the MTO products as classified as *self-inflicted* uncertainty. GMH2 should simply look at the market requirements and set a "reasonable" stable order lead time. Based on the targets from Group, it is suggested that the 12-hour delivery strategy for MTO products are changed app. five days.

Suggestion 2: Differentiate the delivery strategy for the MTS and MTO products. Maintain 12 hours for MTS products. Extend to app. five days for MTO products.

A differentiated view on manufacturing principle and repositioning of the OPP

The current manufacturing principle has been categorized as an ATO-principle with MTS-production in the machining area and MTO-production in the assembly areas. With the overall 12-hour delivery strategy this can be argued to be the only option. In addition, from a theoretical point-of-view it makes sense, due to the modular structure of the pumps in GMH2 [Olhager (2003)]. However, it was argued that the wide product range and many variants somewhat counteracts the benefits of the modular design. (Again, it should be mentioned that the modular design can probably be challenged). The line of thought is here, that differentiating in-housed machined vs. outsourced components and delivery strategy in terms of MTS and MTO products, the manufacturing strategy can also be differentiated. What this implies, is that the MTS products can be manufactured based on a MTS principle (very similar to the current set up) and the MTO products can be manufactured based on a MTO principle.

Suggestion 3: The machining and assembly of MTO pumps should be executed by following a MTO principle and the assembly of MTS pumps should be executed by following a MTO principle

Material flows

Three basic material flows should be set up in GMH2: One for MTS components and one MTO components and one for the fittings e.g. nuts and bolts etc. The components for a MTS pump can be classified into two categories:

1. Main components for the pump e.g. pump housing, motor, impeller, etc.
2. Fittings, nuts and bolts.

None of these components require machining, since it was previously argued that they should be machined by external suppliers.

The components for the MTO pumps can be classified into three categories

1. Cast iron components which need machining in GMH2 e.g. pump housing, motor stools and impellers.
2. Components which does not need machining e.g. shaft, rotor, handle, etc.
3. Fittings e.g. nuts and bolts.

Only the fittings and bolts should be present in GMH2. Here it is not taken into consideration whether it is for a MTO or MTS pumps; hence they are grouped as one and follows the same flow. These should be placed close to the assembly areas and based on a replenishment-system the inventories should be held at an appropriate level. The argument for having these components on stock is that they:

a. Only take up a small amount of space
b. Can easily be lost.
c. Time-consuming to kit accurately.

Now, in terms of the other components, they should be kept on stock outside the production area; hence the external warehouse.

Suggestion 4: Three general material flows are set up in GMH2. One for MTS components, one for MTO components and one for fittings.

Controlling the incoming material flow by kitting

It is suggested that GMH2 introduce "kitting" in the internal warehouse. By kitting the components before entering the production area, GMH2 can control the number of components going in; hence the WIP. The procedure for kitting will be slightly different from MTS pump and MTO pumps, since the kitting process also will follow a MTS principle or MTO principle, respectively.

Suggestion 5: GMH2 control the incoming flow of materials by kitting in the internal warehouse

MTS production

Currently the OPP is positioned in the DCs. However, since GMH2 has no finished-goods inventory, an "internal OPP" is placed in before the assembly process. The planners add MTS-replenishment orders, when the MTO orders for a given day have been completed. This process is more or less untouched.

In terms of the material-flow, the internal warehouse "kit-to-stock". The internal warehouse receives all the components needed from the external warehouse, since all standard components are machined by external suppliers. Basically following the replenishment-system from the DCs, the internal warehouse makes the requested MTS-kits when requested. After the kits have been completed, they are stored either in the warehouse or by the assembly areas, so that they are ready when the planners add the MTS-orders.

Basically the kitting of MTS-pumps functions in the same way as the assembly of MTS pumps functions now: a way to utilize the "kitting capacity" in the internal warehouse, when the MTO kits have been completed. In addition, the “kitting-to-stock” will allow GMH2 to ship the MTS pumps within 12 hours, since only the assembly process has to be commenced.

MTO

Currently the MTO products are produced based on the same ATO-principle as the MTS products. This should be changed. The diagnostic highlighted the amount of WIP inventory present as a result of the ATO-principle. The production of MTO products should be based on a MTO principle in accordance with overall logic presented earlier in this chapter. This entails backwards shifting of the OPP, which as described in “Establishment of Best Practice” will lead to reduced WIP inventory, since production is initiated on actual customer orders.

In terms of the MTO products, the OPP should be placed in the beginning of the internal supply chain, the internal warehouse, where components for production orders should be “kitted to order” – similar to the manufacturing principle for the NK/TPM pumps.

The execution should happen in such a way, that when a MTO customer-order for day X is received in GMH2, it generates the following orders:

1. Shipment-order for day X (Dispatch)
2. Assembly-order for day X-1 (respective assembly area)
3. Machining-order for day X-2 (Machining area)
4. Delivery and kitting order for day X-3 (Ext. and int. WH)

In the following sections, the different processes will be briefly described.

Collection and delivery

Based on the material requirements for the replenishment-orders or production-orders for day X, the external warehouse collects and delivers the required materials. It can be argued that the external warehouse could perform the kitting process, however currently the knowledge, skills or tools are not present to perform the kitting process. In addition, an element of scrap comes into play. For certain components e.g. motors the risk damaging the component increases when removed from the original packaging. It can therefore be argued that the kitting process should take place after the truck-drive. In addition, the element of Q-checks comes into play. A fairly large amount of components require Q-checks upon arrival. By postponing the kitting process, the Q-checks do not increase in complexity.

Kitting and Q-check

The Q-check is basically performed in the current manner. After the Q-check, components for the different customer orders are divided into two main categories:

1. “Ready-for-assembly kits” for the MTS pumps
2. “Ready-for-machining groupings” for the MTO pumps
3. “Additional-component-kits” for the MTO pumps

Notice that the second is actually a grouping. Here the impellers, motor-stools etc. are grouped together due to the current layout. Fig. 28 illustrates the groupings

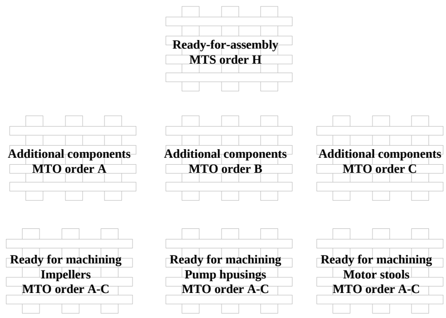


Figure 28: Illustration of grouping and kitting sets

The “additional-components” kits will be put on stock in the respective assembly areas (possibly in a Kardex tower) while the machining-orders put on stock by the respective machining center. The “ready-for-assembly” MTS kits will be placed either by the assembly lines or in the internal warehouse

Machining, painting and “matching” (MTO components)

When the machining has taken place, the components are delivered to the painting area or if no painting is required, they are matched with the additional components in the assembly area.

Assembly

At the assembly areas, there should now be a full kitted set for the assembly orders. The assembly process is carried out as always and the finished order is send to the dispatch area and shipped.

Figure 29 illustrates the concept with the MTS and MTO material flows. In addition the information flow is highlighted.

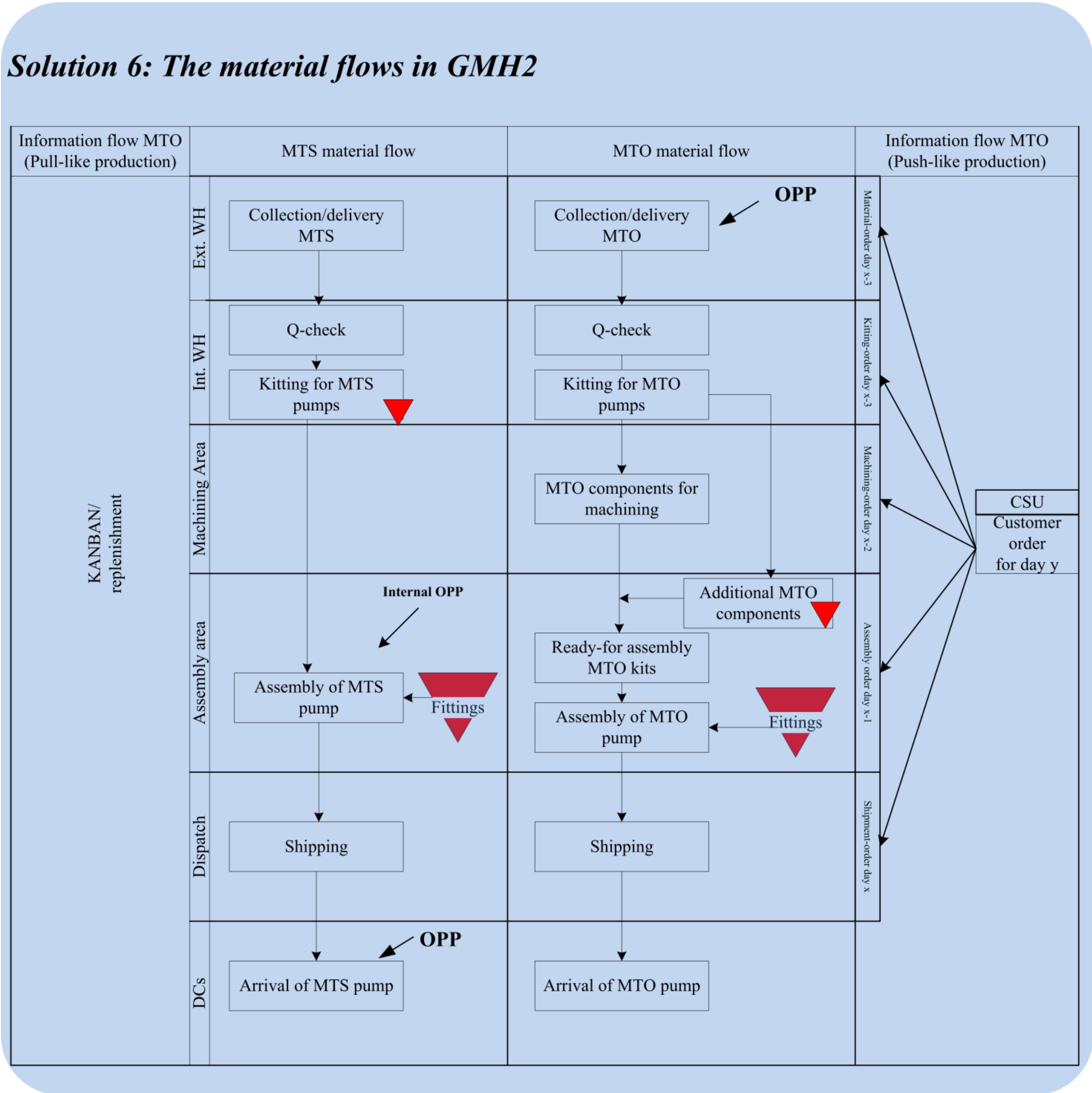


Figure 29: Illustration of the MTS and MTO material and information flow

As it can be derived from figure 29, there are now two different OPPs for the MTS pumps and the MTO pumps. The MTS are manufactured according to a MTS-principle all the way through the internal supply chain and the MTO pumps are manufactured on based on a MTO-principle. By setting up these simple material flows and controlling the amount of incoming goods by kitting the components, the inventory levels are kept at a minimum. At no given time, will there be more components in GMH2, than what is needed for one day's assembly.

The concept with the MTS pumps as "capacity-leveler" is important for this concept to be successful. It is basically the same line-of-thought which is taken place now in the assembly area, it is simply transmitted all the way backwards in the internal supply chain.

As mentioned, it can be expected that some MTS components will be produced in-house in order to level the capacity. After the machining has taken place, the components are stored in the internal warehouse until needed in the kits. If the opposite situation occurs, where the machining of MTO components has to be outsourced, they are simply added to the "additional-component" kits for the MTO pumps.

However, there are four key-issues which must be addressed for these principles to work:

1. The change-over times in the machining area <u>must</u> be reduced
2. Accurate capacity planning in the machining area must be implemented
3. The machining processes must be reliable
4. The BOMs must be accurate

Focus on the change-over times on Multiplex/Integrex equipment

Recall from the descriptive analysis that the FH machines are producing in a 1x1 piece flow. Components are afterwards batched together on Christmas-trees but merely for keeping the components organized and being able to identify them. The situation is a little different with the Multiplex and Integrex machines. When different part numbers (dimensions) of e.g. motor stools or impellers are being machined, the jaws which hold the components in place need to be changed. This is a time consuming process.

The reduced change-over time in the machining provides mix flexibility in the area. With a MTO-principle in the machining area, change-over times must simply be reduced. If the change-over times cannot be reduced, the MTO principle will lead to extreme inefficiency, since very smaller batches (down to 1x1) are being produced. Since the ratio between change-over time and actual production time is large, the cost-structure of the MTO products will be heavily impacted and it is assumed that it is unacceptable. It can be stated that a reduction of change-over times with 80-90% is a prerequisite for the MTO principle to be enforced.

Initiatives such a SMED can be expected to yield results, however the prime result is expected to steem from a technological change.

Flexible jaws

Several pieces of evidence points towards that "flexible jaws" can be implemented on the machines. The area manager of the machining area has previously investigated the possibilities, together with a previous tool-setter, who is now employed by Mazak (the supplier of equipment). The tool-setter is still often present in GMH2, since he is employed as an external consultant. The development phase of the jaws is past design and has been implemented in other companies. Experiences from the consultant show that they work. For unknown reasons, the implementation of these jaws has been stopped in GMH2. One reason could be that when working based on a MTS principle, reduction of change-over times is not vital. Batch production serves the purpose of filling the inventories very well. It is the expert opinion of the area manager that the change-over times could be reduced with 9/10. This change-over time is (close to) equivalent to the change-over time when loading and unloading components of the same dimensions. The difference is the entering of data.

Suggestion 7: Flexible jaws must be implemented on the integrex and multiplex equipment. It has to be proven that the jaws can reduce the change-over times with 80-90%.

Capacity planning

From a planning perspective this has implications. When customer orders are entered in SAP, not only should the assembly capacity be considered, but also the machining capacity.

The changes will primarily be in a SAP-context where the ERP-system needs to be set up accordingly to the manufacturing principle. When a MTO-order is entered in SAP, capacity-checks and updates must be performed on the machining and assembly area. Some capacity planning is taking place in the machining area, according to the PT lead engineer [GSA]. Minor steps have been taken with the introduction of the cover-production for the new SL pump range. This suggests that it can be completed with the current ERP-system.

One of the key issues which will be addressed here is the routings in SAP. The data foundation needs to be accurate in order for the capacity plan to be valid. This requires a thorough examination of the routings and will require discipline to ensure that the data is continuously updated. These tasks are not minor and require dedicated resources; however as mentioned – capacity planning is a must for the MTO principle to work. With no realistic idea about capacity constraints, it can be expected that certain product mix' causes problems. There are several dimensions to this.

Suggestion 8: Capacity planning must be performed not only on the assembly areas, but also the machining area. This requires and examination of the routings and continuous update.

Capacity balancing according to assembly

The assembly area should "set the drum" in general. If the machining area becomes the bottleneck, the assembly areas will have no pumps to assemble. It was argued earlier that MTS components could balance out the capacity need, however only to certain extend. The "rule of thumb" should be:

"The assembly area set the drum. The machining area must have the required capacity to supply to the assembly areas".

What this implies, is that a lead-capacity strategy is applied in the machining area according to the demand of assembly area. It must be accepted that some capacity losses are occurring in the machining area to ensure that the capacity in the assembly areas are filled despite the various MTO-product mixes.

Horizontal capacity balancing in the machining area

Another dimension is that capacity should be balanced "horizontally" in the machining area. What this means is that the capacity of the impeller machinery should match of the capacity of the pump housing machinery, etc. This will require careful examination and consideration in terms of which MTO components are produced in-house and which components are outsourced.

It is suggested that a group of part numbers are chosen to function as these "capacity fill up" components. It is expected that different mix of components through the machining area will lead to different levels of capacity utilization. However, it should be mentioned that only a limited number of components are chosen and appropriate inventory levels are set up. If the capacity balancing is not functioning, the mix of outsourced and in-house produced should be reconsidered.

Suggestion 9: A lead-capacity strategy should be implemented in the machining area, so that the assembly processes "set the drum". A group of standard components should be selected to function as "capacity fill-up" components to ensure acceptable capacity utilization

Focus on unreliable processes

On managerial level, there exist some concerns with the machining processes in GMH2. Machine breakdowns can probably not be avoided completely. Murphy's Law states: *"If things can go wrong they will go wrong."*[Boer, lecture AAU].

GMH2 has already implemented TPM (Total Productive Maintenance) to prevent frequent breakdowns. However, with basically no buffer inventories (since only the needed materials are brought into GMH2) one could argue that TPM should receive further attention to ensure reliable processes.

Contingency routings

An additional opportunity for GMH2 is to develop "contingency routings" in the events of machine breakdowns. The machine park is relatively homogenous with several machines of the same type. This is a great benefit. If one machine breakdowns, it should theoretically be possible to machine the component on an equivalent machine. One of the problems is that currently there are no explicit routing maps showing which components can be produced where. These should be developed as a way of ensuring "*process flexibility"* with the relevant software installed on the different machines.

This also leads back to the lead-capacity strategy. There is no doubt that with a reduced WIP inventory, GMH2 is more sensitive to these kinds of disturbances. However, instead of inventory as the buffer, exceed capacity on equivalent machines are applied. In case of no breakdowns, the exceed capacity can still be applied producing the "capacity fill-up" components.

Suggestion 10: GMH2 needs extensive focus on TPM to ensure a low number of breakdowns. In addition, "contingency-routings" should be developed to ensure process flexibility. The lead-capacity strategy functions as a buffer instead of large WIP inventories.

It can be expected that the production can be carried out with only the needed components actually entering GMH2. The WIP inventories are reduced significantly and the capacity of the machining area is utilized for machining of components on which there exists an actual order.

Focus on inaccurate BOMs

The last prerequisite addressed in this solution suggestion is the BOMs. If the BOMs continuous to be flawed it will be impossible to kit the correct components. If kitting, supposedly based on BOMs it is a must that they are correct and continuously in focus for updates etc. It is a question of priorities, and if there is a desire to run a production with minimum levels of inventories, the data foundation must be accurate. This is very similar to the accurate routings in SAP if the capacity planning should be expected to function.

Suggestion 11: The BOMs must be accurate in order for the production in GMH2 to function where incoming materials are controlled by kitting. This is a matter of discipline but also prioritization of tasks

Sum up on solution suggestions

The suggestions presented throughout this chapter span on different organizational levels and can all be related to the matters of simplicity and discipline. Fig. 30 sums up the suggestions.

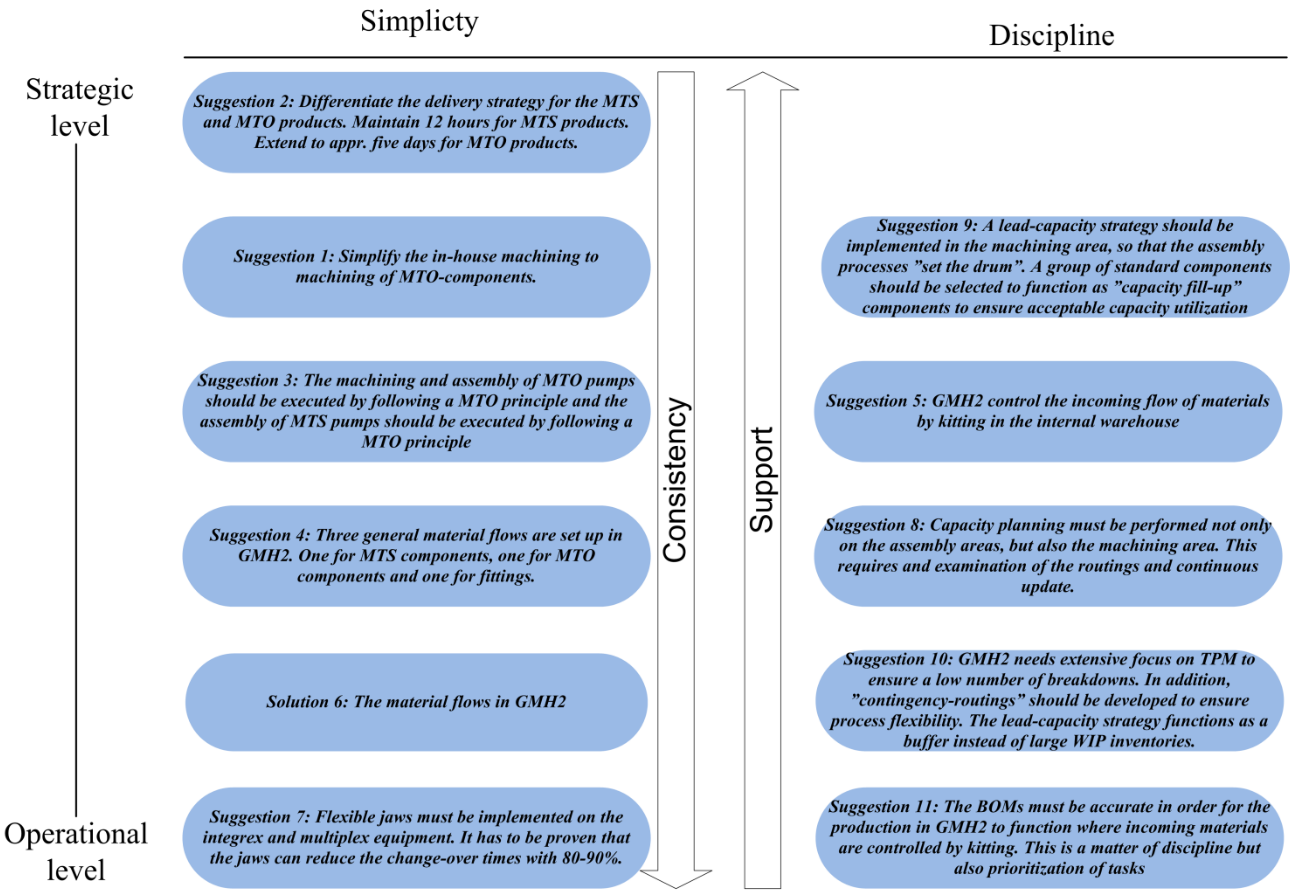


Figure 30: Illustration of how the solution suggestions are placed from a strategic level to operational level. The purpose is to create consistency and support between the suggestions

12. The sequence of execution

The following chapter strives to provide input o the sequence of implementation. It should not be view as an actual implementation plan, merely provide the basis for one.

General comments

Even though the solution suggestions rely on simplicity and discipline, the implementation of suggestions will not be an easy task for GMH2. The root-causes identified are deeply rooted in the core of the organization. It can more or less be classified as a new production concept, where the reliance and flexibility of inventory, is substituted with reliance and flexibility of simplicity and discipline. However, the changes can be performed sequential and if attacking the task at hand "one step at the time" it should be possible to complete.

The prerequisites

It was argued in the solution suggestion that a few of the solutions were actual prerequisites, in order for the more strategic and conceptual suggestions to be implemented.

Change-overs

The first step should be to address the change-over times of the integrex and multiplex machines. As mentioned, is should be verified that the equipment is capable of producing in a 1x1 flow without massive penalties in actual production time.

The process of testing and implementing the flexible jaws can be expected to be time consuming: Tests, software-updates and training of operators constitute some major tasks in the implementation of the jaws. In addition it must be verified that the quality of the products are not hampered by implementing the jaws. In addition, GMH2 should benefit from the fact that the jaws are currently close to fully developed and a complete development phase is not required. It cannot be disputed that a reduction of around 90% of the change-over times will lead yield some substantial gains given the number of components (over 200.000) produced yearly on the integrex and multiplex machines and should be implemented no matter what.

Correction of BOMs

This task is more straightforward, and should be completed no matter what. The BOMs are an important part of the data foundation in GMH2 and the inaccuracy are costly in terms of time and resources but can also be expected to affect the quality of the final pumps. It should be a top priority to ensure that the BOMs are accurate. In addition, it should be investigated how to ensure that the problem is not reoccurring in the future. Control mechanisms should be implemented to ensure a fast correction of the BOMs in case of material changes.

Capacity planning in SAP

Setting up SAP to make accurate capacity planning is also considered a prerequisite for the solutions proposed. From an ERP-system point-of-view it is definitely possible to complete within relatively short period, assuming that the people with sufficient knowledge about capacity planning can be located. SAP consultants are expensive; however on the other hand resources might be available inside GMH2 or within the Group.

The largest challenge however, lies within the updating of the data in the system to ensure it is up-to-date. Without accurate data regarding process times, change-over times, dedicated time for TPM etc., the capacity plans will be inaccurate. This cannot be tolerated since it will lead to stops in the production flow and decrease important performance measurements such as “delivery reliability”. In addition, the data require constantly maintenance in order for the ERP system to be up to date.

Reliable processes and contingency plans

The fourth and final prerequisite is the improvement of process reliability and development of contingency plans/routings. When attempting to set up a production-system where safety and back-up inventories are virtually removed, the processes need to be reliable. The focus on TPM should increase and operators and relevant employees should be trained in the TPM procedures etc. In addition, the development of contingency plans is a must. It cannot be expected that breakdowns and failures can be completely eliminated, and therefore alternative routings must be developed. Given the relatively low number of different equipment, and the multiplicity of the same equipment, this task can be classified as one of the easiest.

Parallel implementation of the prerequisites

These four suggestions can be implemented parallel. This is a benefit since it will speed up the process. One of the obstacles to overcome, however, is to ensure that there are sufficient and dedicated resources to complete the task. Experiences, especially from the lean program, indicate that GMH2 has difficulties setting up dedicated project teams that can complete such tasks.

Project teams

With respect to the change-over reduction, correction of BOMs and process reliability, primarily production and engineering resources should be allocated to the relevant project team(s).

With respect to the capacity planning in SAP, a more cross-functional team is required. Resources from CSU, production, engineering and IT should join forces to solve this task. It is important that input from several perspectives are included so that the data matches the realities in GMH2. In addition, training of the users should be undertaken to ensure that the system is used correctly.

The time is now

Given the current downswing, one can argue that now is the time to complete these tasks. Given the reduced order in-take resources should be available within GMH2 and one can argue that GMH2 has the opportunity to prepare for when the order in-take increases again.

Sustainability

A key issue is sustainability. It is important to mention that “maintenance” is required to ensure that data and procedures are constantly up-to-date. What this mean is that not only should resources be allocated to implementing the suggestions, resources should also be allocated to maintaining the suggestions. Again, experiences from the lean program show that GMH2 has difficulties anchoring changes in the organization. Yet again, the improved results in delivery reliability show that they are capable of performing and anchoring change initiatives if the appropriate resources are allocated.

A test

Given the disciplinary nature of three of the four prerequisites, successful completion and sustainment of the prerequisites will give GMH2 the opportunity to evaluate whether the organization has the discipline to run a production with a minimum level of WIP inventories as safety and flexibility net. It can be argued that these three steps perhaps are the most difficult to overcome and implement in sustainable manner. Here management plays an important role. Motivation, information, communication, support and “leading by example” are some of the key-words in the “Change management” literature [Lassen, lectures AAU]. This study does not include an evaluation of different change-management models and strategies available to

GMH2. The comments connected to this subject will be limited to stating that if these changes are to be implemented; management must understand that the fundamental building blocks are the people. The employees in GMH2 are expected to change their behavior to some extend and obtain and develop a more disciplinary attitude especially towards the maintenance of data. This development should be based on understanding and commitment. Otherwise sustainability will not be obtained.

Practicing and obtaining knowledge to support MTO production in the machining area

After successful implementation of the prerequisites, focus should be directed towards the machining area. The components machined in-house should strictly be MTO components as suggested in first solution suggestion. With capacity planning in place, GMH2 will have a chance to practice the capacity planning in the machining area and start to get a feel for whether the current number of MTO components matches the capacity of the area, or whether components should be either outsourced or in-sourced. It is important that different mixes are observed and investigated so that GMH2 obtains knowledge where, when and what “capacity fill-up” components should be set up. In addition this will allow GMH2 to verify the capacity modules set up in SAP, so ensure that they are accurate.

Defining accurate capacities

In addition, the lead-capacity strategy should slowly take form with the identification of how the capacity in the machining matches the capacity in the assembly. Remember that the assembly areas should set the demand, so some exceed capacity should be available in the machining area. In addition the “horizontal” capacity balancing in the machining area should be investigated.

This will also give clear identification and possibilities to calculate how affected the machining area will be penalized in terms of capacity. This will have an impact on the decision to carry out the remaining suggestions.

Sequence by components

An opportunity lies with the sequential implementation in the machining area e.g. first the impeller machinery, then pump housing etc. Again, this will decrease the complexity of the task and constantly allow GMH2 to monitor the effects and consequences.

Project teams

Cross functional project teams should be used in these steps. Planning, production, engineering, purchase, quality and logistics input should be considered when striving to implement the changes.

The implementation of concepts and strategies

With the foundations in place and an overview of the capacity in the machining area when strictly operating with MTO components, GMH2 can now consider implementing the simple material flows, introducing kitting and the differentiated delivery strategy for the MTS and MTO components.

The line of thought is here that the differentiated delivery strategy allows for differentiated simple MTS and MTO principles. This should be supported by the visualization of the simple MTO and MTS flows again supported by the kitting processes in the internal warehouse. In terms of these suggestions, it seems that they should be implemented simultaneously in order to ensure consistency, maximize the benefits and achieve the needed support. However, GMH2 has the opportunity to again implement the changes product range by product range.

Pilot projects

As mentioned previously, the production of NK/TPM pumps already make use of a MTO-principle in terms of the impellers. This seems to be an appropriate starting point. By passing on the MTO principle from the impeller production to the other in-house machined components, GMH2 will slowly built up the required knowledge required to implement the changes on the other product ranges. The complexity will increase when implementing the changes on the ranges where both MTS and MTO pumps are produced. It is therefore important that the "easier" pump ranges are subjected to the changes initially, to cure as many "child-diseases" as possible. Among possible solutions for child-diseases, control mechanisms in the kitting process, contingency plans in terms of late deliveries etc. can be mentioned.

Additional comments

The operational implication will span the entire organization of GMH2, including the suppliers and customers, with special focus on the external warehouse and the DCs. It is important that these are included in the change process as well. Procedures and processes undertaken in the respective organization can be expected to also require adjustments to fit the new and improved production flow.

It is very important that GMH2 recognizes the complexity of the task at hand and allocates sufficient and dedicated resources in cross-functional teams to set up the operational procedures etc., to ensure that the production flow will not be continuously interrupted.

Sum up

The sequence of execution can be depicted as in fig. 31. It is estimated that the change process would last around three years, depending on the allocated resources.

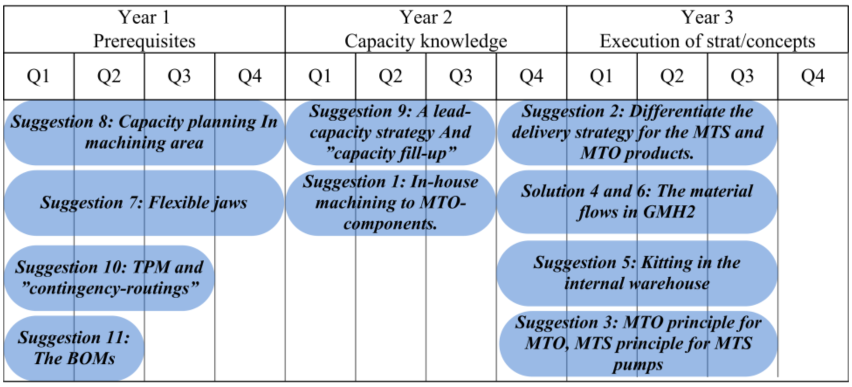


Figure 31: A proposal for sequence of execution

13. Expected gains

The following will provide some estimations of what GMH2 can expect to gain from implementing the suggestions in terms of SQMs and impact on area utilization.

As showed in the ”Sequence of implementation” it is a rather comprehensive change process which is suggested, and around a three year time period could be expected for implementing the changes. However, some substantial gains could also be expected.

A few layout related comments

In order to give a rough estimate of how many SQMs could be made available in GMH2, two ideas should be mentioned: additional Kardex towers and storing of small components under the windows.

Kardex towers

GMH2 applies Kardex towers a various places in GMH2. The towers are vertical inventory systems. The tower contains a number of trays and is basically functioning as a carousel. Pic. 9 shows a tower.

Picture 9: Kardex tower/inventory system

The idea is, that with the reduced amount of WIP, GMH2 stores the kits in the towers. This would release SQMs since the height is utilized. A number of towers (depending on needed capacity) would be placed in each area. For simplicity reasons it is assumed that two towers would be sufficient to store the WIP for each assembly area, and four would be needed in the machining area.

Placement of small components

As mentioned, the fittings are kept on stock in the assembly areas. There is a possibility to use a tray in the kardex towers for the fittings; however another solution is also possible. Small containers could be placed around the walls in GMH2. This would allow the operators to get quick “ad hoc” access to the small components. The concept is already applied in the TP100-200 area. Pic. 10 illustrates the idea:

Picture 10: Small components along the walls in GMH2

With presentation of these two ideas, it is possible to make some estimation of how many SQMs could be made available for production

Elimination of inventory in internal warehouse

One of the most noticeable gains would be a virtual elimination of the inventory in the internal warehouse. As mentioned, some inventory would be needed for fittings and the "capacity fill-up" components. In addition, scrap components still need to be stored until taken care of etc. Furthermore, space would be needed for the kitting process. It is assumed that four Kardex towers would be enough for storing the components and the area needed for kitting would mainly be the area needed for loading and unloading, however with some additional SQMs. Some thorough layout consideration would yield more accurate results.

WIP in the production areas

As mentioned, it is assumed that WIP (kits) are stored in Kardex towers and two towers yield the sufficient capacity for each assembly area and four is needed for the machining. In addition racks with small components are needed along the walls.

Packaging materials

As mentioned in the limitations sections the packaging materials have not been under investigation put it is also assumed that a more JIT-like approach could be implemented. For now the inventory occupied with packaging materials is untouched.

Walking space between inventory racks and shelves

The SQMs between the inventories is also assumed to be made available for production. The SQMs are no longer needed if the inventory is removed.

TP400 area

In terms of the TP3 test bed (TP400 area) it is assumed that many of the components are actually to large to go into the towers. The WIP in that area is for now untouched.

Illustration of impact of solution suggestions

Fig. 32 illustrates where in GMH2 inventory is removed and some possible location for Kardex towers. The SQMs made available are marked with blue. The red is inventory, green "value-adding SQMs", and the yellow/orange is the walking space and major roads. The area within the dotted line is expected to be used for kitting of components.

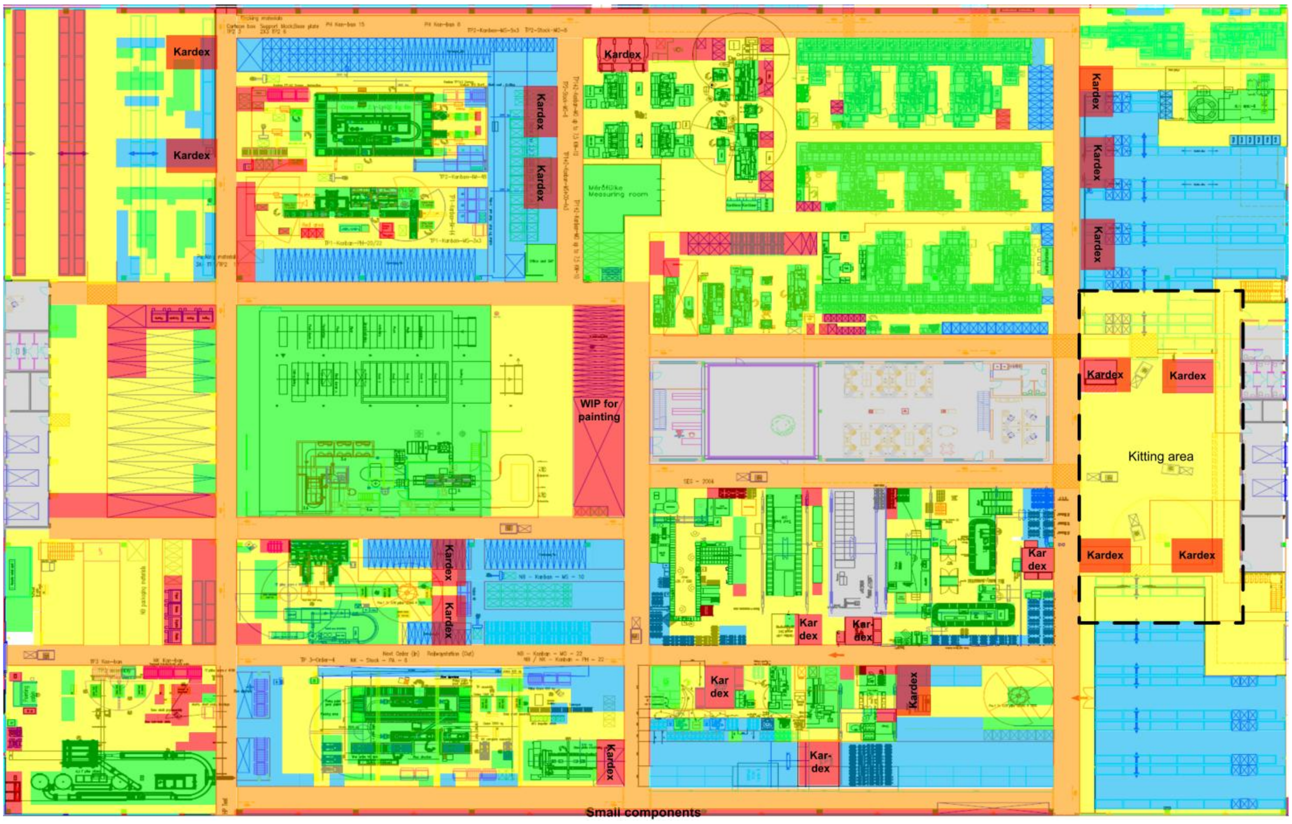


Figure 32: Illustration of impact of solution suggestions. The blue areas indicate the SQMs made available for production

The point is here, to illustrate visually roughly the amount of SQMs GMH2 can make available by implementing the suggested solutions.

Numeric estimation of SQM benefits

With reference to the area utilization analysis in appendix B1some rough estimations can be made. With reference to Fig. 32, the WIP in the machining area is practically untouched, since the MTO components still have to be stored between processes when they are being machined. The big gains are in the assembly areas and in the internal warehouse. The estimations are presented in table 13, with the previous SQMs occupied with inventory are the numbers in brackets.

Analysis 2008 [m²]					
Area	Equip. & ass. stations	Inventory	Work/ walk space	**Available SQMs**	Major roads
NK/TPM	195	30 (160)	245	**130**	N/A
NB	85	45 (225)	170 (240)	**250**	N/A
TP100-200	75	30 (75)	150	**45**	N/A
TP300	155	90 (390)	385 (455)	**370**	N/A
TP400	150	40	210	**0**	N/A
WW	270	100 (150)	330	**50**	N/A
Spare parts	20	15 (65)	115	**50**	N/A
Machining	900	200	900	**0**	N/A
Impeller cell	70	40 (100)	100 (130)	**90**	N/A
Painting	650	140	260	**0**	N/A
Warehouse 1 (incoming)	0	60 (510)	570 (990)	**870**	N/A
Warehouse 2 (Packing)	0	130	170	**0**	N/A
Warehouse 3 (Additional)	0	0 (65)	0 (35)	**100**	N/A
Finished goods area	20	0	430	**0**	N/A
Packing area	50	0	250	**0**	N/A
Major roads	0	0			2200
Total GMH2:	2640	920 (2250)	4285 (4910)	**1955**	2200

Table 13: Numeric estimation of SQMs made available

It is estimated that roughly 2000 SQMs can be made available from implementing the suggestions. These are found purely from removing inventory and the walking space required to access the inventory. The largest gains are found in the internal warehouse. This was expected since the purpose of the warehouse is redefined to focus on the kitting of components. In addition, the TP300 and NB areas show remarkable gains. This was also expected since these were the areas with the largest concentrations of WIP inventory. It can be expressed in the following pie-diagram:

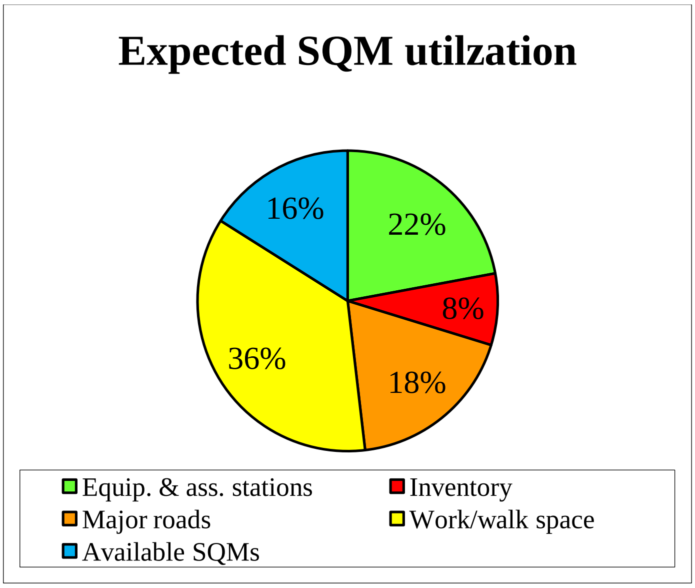


Figure 33: The total shop floor in GMH2 with the potential SQMs made available

As it can be viewed from the diagram, the inventory has been reduced to from 19% (2250 m^2) to 8% (920 m^2) of total shop floor area, and the working/walking space has been reduced from 41% (4910 m^2) to 36% (4285m^2).

Estimating what it is worth

It is important to mention, that in order for GMH2 to benefit from the reduced SQMs, some layout changes should be considered. The reduced inventories open up for some possibilities for reconsidering the layout, and make room available for additional production. However, as showed in the area utilization analysis, some figures can be attached to the SQMs.

Area utilization as defined by GMH2

Recall the definition of area utilization:

$$Area\ utilization = \frac{turnover}{m^2} pr.anno$$

The analysis in appendix B1 showed that on an overall level, GMH2 has an area utilization of:

$$Area\ utilization = \frac{117.000.000\ €}{12.000\ m^2} pr.anno \quad = \underline{\underline{9.750\ €/m^2\ \text{pr. anno}}}$$

The SQMs in GMH2 has not been reduced, but it can be argued that the utilized SQMs have been reduced, leading to the following calculation of the area utilization:

$$Area\ utilization = \frac{117.000.000\ €}{10.000\ m^2} pr.anno \quad = \underline{\underline{11.700\ €/\text{m2 pr. anno}}}$$

It was argued previously that the benefits of the available SQMs are not realized until they are actually used for production purposes and also what actually is being produced. If it is assumed that the available SQMs are applied for production of range(s) which on average would yield the same turnover as the current mix in GMH2, it can be argued that available SQMs found by reducing the inventory yields a potential turnover increase which can be expressed as:

$$11.700\ €/m^2\ \text{pr. anno} * 1.955\ m^2 = \underline{\underline{€23M\ \ \text{pr. anno}}}$$

This clearly shows that there could be some substantial economic benefits in reducing the SQMs occupied by inventory and replace them with actual production. Notice that the 11.700€/m^2 pr. anno is not “pure” value-adding space. Since the number is based on the entire GMH2, room for work/walking space and packaging inventory is included.

In addition, the capital tied up in inventory will drop significantly. These numbers should be available for GMH2.

An important note

It is important to remember that these numbers are based on the turnover figures from Q3 and Q4 2007 and Q1 and Q2 2008. Due to the crisis the turnovers have dropped and should be considered when applying these numbers.

14. Discussion

This discussion serves to make some general comments about the solution suggestions. In addition, the solution suggestions will be evaluated against the factors of "Practicability" as mentioned in the Study Design.

Flexibility and variety

The suggestions presented take their starting point in some "deep" root-causes in GMH2's organization. It was highlighted in the diagnostic that the inventory is GMH2 exist for two main purposes:

1. As a way of matching variety with flexibility
2. As a result of increased complexity

The solution suggestions therefore propose alternative ways for GMH2 to be flexible. This was described as the "rigid flexibility model" where simplicity and discipline constitute the foundation. There is double effect in implementing the rigid flexibility: complexity is reduced as a result of simplicity on an operational level.

In addition, the diagnostic showed that some of the variety that GMH2 is exposed to is "self-inflicted". Again, as a result of implementing simplicity on a more strategic level, GMH2 reduced the variety they are exposed to.

Focus on long-term instead of short-term

There is no doubt that the magnitude of the solution suggestions can be classified as radical. It will take a lot of courage and commitment to change the way the production system is set up. The question is: could simpler and smaller changes within changing the current set up decrease the level on inventories? The answer is "yes", but only to a certain extend.

One could argue that GMH2 should continue to follow the MTS-principle with respect to component machining, and the MTO-principle in the assembly areas. Then by tuning and improving the inventory levels in the KANBAN system and set up a system based on a pull principle, a drop in inventory levels could be expected. However, it does not change the fact that as a result buffer inventories would be present in GMH2 to "glue" the machining and assembly areas together.

Given the range of pumps and number of variants, there is a limit to what minimum inventory levels GMH2 can reach with a MTS-principle in the machining area. It has been left out of this study to investigate the modular design of the products, but it seems that the benefits standard modules would theoretically have on the required inventory levels, are counteracted by the many variants. Given the current modules, it is simply impossible to reduce the WIP as drastically as the solutions here propose with an ATO-principle in place in GMH2.

Another argument for attacking "deep" in the organization is that the complexity and inventory levels can only be expected to increase if (as mentioned in the introduction) GMH2 should add new product ranges to their portfolio. Additional components would have to be kept on stock and additional safety inventories would have to be placed in order to match the increased uncertainties and variety. As mentioned, [da Silveira (2003)] highlights this phenomenon: Inventory works very well as a measure of flexibility to match variety – but only short term. The complexity the inventory adds and the lack of focus on simplicity and discipline simply cripples the organization with respect to long term growth.

It is the opinion of the author that this phenomenon very well describes the situation in GMH2. Due to rapid growth and lack of focus on simplicity and discipline, GMH2 now finds themselves in a situation where long term growth is limited – unless the strategies, concepts and principles are redefined to embed simplicity and discipline.

Compatibility (first factor of practicability)

When looking at the proposed changes, an important question can be asked: Does these solution suggestions fit GMH2 as organization? There are a couple of sides to the answer of that question.

On one hand, GMH2 can be expected to posses the majority of the skills, knowledge and technology required to implement the changes. Given the simplistic nature of the solution suggestions, this could be expected. However, the suggestions also propose a new approach to discipline where best practices are followed throughout the organization. In addition, the magnitude itself of the suggestions also raises some concerns with the author of this report

Performance measurement

GMH2 is under pressure from the Group to perform and various KPIs. This type of control is termed "KPI-control". The reason for the concern is the fact that a solid foundation must be built before GMH2 can implement actual changes which decreases the levels of inventory. Fig. 34 depicts how the suggestions can be expected to "pay off".

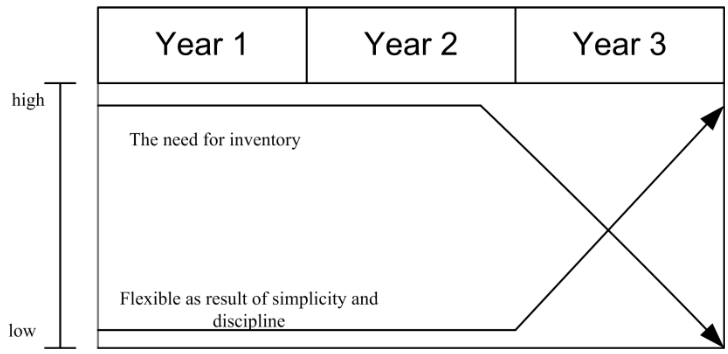


Figure 34: Expected pay off curve of suggestions

This is not really "in tune" with the "KPI control" in GMH2. For logical reasons, the management in GMH2 is focused on getting visible results to the KPIs in order to fulfill the different KPI-related goals. This is definitely understandable but it also implies that there is task for the management, to convince the Group that (long-term) investments in simplicity and discipline will pay off in the long run, but not yield quick results in the short run.

Change management

Another task lies in front of the management in GMH2, should they decide to implement the solutions proposed. In order for the solutions to be successful, there is a need to change the "organizational mindset" (or culture). The tasks of implementing the e.g. the simple flows or the flexible jaws is relatively simple compared to anchoring the discipline required to run a smooth flexible production without inventory. Putting it a little "black on white" one can argue that the inventories are partly there because "almost", "nearly" and "close to" is accepted in GMH2, contra "exactly", "precisely" and "accurately". This task should not be underestimated. The following quote sums up what is meant:

"At least 70% of major corporate changes fail to capture the benefits ascribed to them. A big factor is that the ***soft issues*** *are not understood to truly be the hard issues. Not enough attention is dedicated to the hearts and minds of the people in the organizations" – Glenn Tilton, CEO, UAL [Lassen, lecture AAU (2008)]*

The aspect of change management is extremely important in this context. As mentioned in the "limitations" the aspect of change management has been discarded in this study due to time constraints. But it certainly does not make in unimportant. When making changes in this magnitude, the minds and commitment of the employees, is the key. It is important to understand, that it is not only technological changes that are undertaken. It is also the work routines of the employees which should embed the discipline required to anchor the suggestions in the organization.

The key change-agent is the management, who has to lead-by-example and show the commitment and support of the change process [Lassen, lectures AAU (2008)]. GMH2 has to decide whether the required resources are available, but this is certainly also on a management level.

Consistency (second factor of practicability)

Consistency has been a key-theme throughout the solution suggestions. The suggestions have strived to encompass consistency between markets and business strategy, strategy and principles, principles and processes/products. Another type of consistency which can be discussed is between the findings of this study and the current concepts and programs in GMH2.

BE (TQM) and rigid flexibility

There is found no evidence that the elements of BE does not fit the elements of rigid flexibility and the suggestions proposed in this study – on the contrary. TQM stresses the need for well-defined processes to make improvements possible. These improvements should be targeted towards the customer. This is very similar to the idea proposed in this study: By setting up simple processes, procedures and flows and anchoring the discipline to uphold these, GMH2 will be able to minimize non-value adding SQMs. The suggestions incorporate the demands from the market and take this as the starting point. It can definitely be argued that rigid flexibility is a part of the operational excellence that GMH2 is striving to achieve.

Lean and rigid flexibility

The lean program is currently still in the start up phase. The operational suggestions mentioned throughout this study seem in general terms to match the characteristics of a lean program: standardized work, visible flows, reduction of change-over times etc. It should definitely be considered to incorporate the ideas presented in this study in the lean program.

Positioning the study

When looking at the overall goal for this study: the reduction of inventory, there is a great opportunity to position the result of this study within the programs already running in GMH2. The programs seem to support each other in various ways and there is an opportunity to obtain synergies. When looking at e.g. the anchoring of discipline, there seems to be a close connection to the implementation of standardized work. A project coordinator, with insights in the different programs running in GMH2 should be found to ensure that the programs benefit from each other. In the same way that "streamlining" was found to be important with respect to e.g. material flows and strategies, the programs in GMH2 should be streamlined as well.

Feasibility (third factor of practicability)

It was estimated that roughly 2000 SMQs can be made available for production by implementing the suggestions. In addition, capital tied up in WIP would also account for an important gain. However, it was also showed that implementing the suggestions would be a time-consuming (estimated three years) process. In addition, layout considerations should be included to maximize the benefits of the solutions.

This will be a costly process especially in terms of resources. The investments required are somewhat limited, yet the Kardex inventory towers are not expected to be cheap. However, it was also argued that if 2000 SQMs could be made available for production, around €20,0M could be expected in addition yearly turnover. These calculations should be performed on a more detailed level, yet there seem to be good indicators that implementing the suggestions would be beneficial for GMH2 in the long-term.

Improving or investing

During the course of this study, some calculations were made in order to see what it would cost to build up a factory similar to GMH2. It was estimated that €36M is the investment costs for setting up a factory similar to GMH2. It is important to mention that this cost is without land-acquisition costs. This gave led to estimation, that 1 SQM cost roughly €3000 to set up.

Just as “a pointer”, this implies that making 2000 SQMs available for production by investing in a new factory would be around €6M.

It is “guess-timated” that the cost of implementing the proposed solution would far less than €6M. Again, more thorough economic calculations should be done in order to ensure the feasibility of the suggestions. The numbers only show that there is reason to investigate it further.

Robustness (fourth factor of practicability)

Robustness is very much related to the “discipline” factor mentioned throughout this study. There is no doubt that GMH2 needs to anchor and maintain the level of discipline required to run a smooth production without inventories. As mentioned previously, this is a comprehensive task where the culture of the organization will have to be changed in many ways. Again, the role of management is pointed out. It cannot be stressed enough how important it is that the management show commitment and support for the initiatives and communicate to the rest of the organization why the things are happening [Kotter (2008)].

Sum up on the factors of “practicability”

As mentioned in the study design, “practicability” will be used to address whether the solution suggestions are “sound” in the context of GMH2.

In terms of *consistency* and *feasibility* the author of this report does not have many concerns regarding the solutions proposed in this study. There seems to be consistency between the suggestions and the market conditions and concepts which are running in GMH2. In addition there are indicators that from a feasibility point-of-view, that there could be good economic incitement to implement the proposed suggestions.

The concern lies with *compatibility* and *robustness*. The author of this report is not sure whether GMH2 will be able to change the disciplinary-level required to benefit from the solutions. There seems to be a fairly huge gap from where GMH2 is now to where they need to be if the suggestions should be successful.

This does not mean that GMH2 should not do it. It simply means that there lies a great task in front of the management in GMH2. They will have to be the front-runners and commit to these suggestions 100%.

Additional comments

A few additional comments will be made as a round of to this discussion. It is some considerations that should be made with respect to the proposed solutions.

Layout consideration

It was mentioned previously, that in order to fully benefit from the reduced inventory in terms of available SQMs, the layouts in GMH2 should be considered. With the removal of inventory some new opportunities will present itself in terms of how many SQMs should be allocated for the different areas. Opportunities for “squeezing” areas together should be considered. In addition “turning” the areas might open up some new opportunities for improved flow.

Practical implications

It should be mentioned that not all practical implications have been considered in this study. This should be view as a proposal on a more conceptual level. Issues with quality, scrap movement of components etc. should be investigated further. The time constraint on this study has not made it possible to consider all these issues. It can be expected that several processes and procedures must be redefined according to the new principles in GMH2.

15. Conclusion

The sole purpose of this conclusion is to sum up on the study by answering the four working questions related to the second part of the report, as presented in "Study Objectives"

What are the possible solutions to the root-causes?

It is suggested that GMH2 focus on simplicity and discipline, the ground pillars of the "rigid flexibility model" [Collins & Schmenner (1993)] to gain the flexibility needed to match the variety exposed to GMH2 from the market. In addition, there is evidence that GMH2 is currently self-inflicting variety on their organization; hence creating an extended need for flexibility. It can be summed up in the following statement:

GMH2 is currently trying to do everything all time, instead of doing the right thing, in the right time.

Reducing variety

Currently GMH2 is operating with a 12-hour delivery strategy. This short production horizon creates uncertainty and virtually limits their possibilities for synchronizing their delivery and production processes. By streamlining their delivery strategy to the market needs, GMH2 can operate with a 12-hour delivery strategy for the MTS-products and a five-day delivery strategy for the MTO-products, and still fulfill the customer demands.

By differentiating the delivery strategy, GMH2 can differentiate their manufacturing principles accordingly. Primarily from a cost-perspective, GMH2 should outsource the machining of components for the MTS-pumps and keep the machining of components for MTO-pumps in-house. This will narrow and focus the purpose of the machining area: to supply the assembly areas with MTO components based on a MTO-principle.

GMH2 should introduce kitting in their internal processes, mainly to control the incoming flow of materials. The kitting process should likewise be differentiated between MTS and MTO. Throughout the internal supply chain, the MTS components are used as "capacity-balancers" to ensure an acceptable level of capacity utilization.

To change the machining area from operating based on a MTS-principle to a MTO-principle, GMH2 needs to focus on reducing the change-over times of the equipment. Evidence suggests that it is possible to produce in a 1x1 flow with no significant penalties to capacity. However, capacity penalties are expected since the capacity strategy for the machining area should be changes to a lead-strategy to ensure fulfillment of the assembly areas demand.

By focusing and simplifying their strategies, principles and processes, GMH2 will obtain simple material and information flows which embed the flexibility required to match the variety of the markets. This type of flexibility can be expected to be more beneficial in the long-term, since the reduction of inventory combined with simplicity of strategies and flows, untangles GMH2 from the complexity, which is believed to currently cripple them from long-term growth.

The simple processes and procedures should be uphold and sustained with discipline. An organization based on best practices will ensure that GMH2 removes the internal variety currently embedded in unreliable processes. This task is not a simple one, and the management in GMH2 has to be the front-runners if the change initiatives are to successes.

What will be the effect on the SQMs and area utilization?

GMH2 can expect to make app. 2000 SQMs available for production by removing the inventory and create their flexibility from simplicity and discipline. GMH2 would reduce the SQMs occupied by inventory from 2250 SQMs (19% of the shop floor area) to 920 SQMs (8% of the shop floor area). The remaining 700 SQMs would be from reduction in walking space. In addition, GMH2 can expect to untie capital tied up in WIP. In terms of area utilization as defined by GMH2, GMH2 would increase the area utilization from €9.750 to €11.700 (or 20%), in the sense that they only utilize 10.000 SQMs, and have 2000 available for production.

How should the suggestions be implemented?

GMH2 should implement the changes as a three step process. The initial steps should be to ensure that the prerequisites are in place:

- Reduction of change-over times on the integrex and multiplex machines by implementing flexible jaws (solution 7)
- Update the data in SAP and commence capacity planning in the machining area (solution 8)
- Update the BOMs (solution 11)
- Focus on decreasing the unreliability of the internal and delivery processes and develop contingency plans to create process flexibility (solution 10)

The second steps should be obtaining knowledge regarding the capacity of the machining area in terms of machining of MTO components based on a MTO-principle:

- Outsource the machining of MTS components and strictly machine MTO components in-house (solution 1)
- Evaluate the machining capacity when producing MTO components, and adjust the capacity to the assembly areas by in- or outsourcing MTS/MTO components. Follow a lead-capacity strategy (solution 9)

The third step would be an implementation of the differentiated production strategies, principles and flows. In addition “kitting” is introduced

- Differentiate the delivery-strategy for MTS and MTO products (solution 2)
- Differentiate the OPP for MTO and MTS products (solution 3)
- Set up simple material flows for MTO and MTS products (solution 4 and 6)
- Introduce kitting in the internal warehouse (solution 5)

The suggestions should be implemented as part of the running programs (BE and Lean) and can to a large extend be implemented sequential – at least for the first steps. Throughout the process, pilot projects and isolated implementation on different product ranges can be used to cure “child-diseases” and set up control mechanisms.

What are the expected benefits and costs?

The expected benefits are strongly related to the SQMs made available for production (2000) and the effect on area utilization. However, it is a must that the available SQMs are used for production purposes. In addition, GMH2 will be based on simple, streamlined strategies, principles and processes which will allow for overview and transparency. Long-term growth will be made possible e.g. by considering the layout of the factory and implementing similar suggestions on the inventory of packaging materials.

The expected costs should be calculated on more detailed level, however comparing to the investment price of roughly €3000 pr. SQM for building new SQMs (setting up a new factory), it can be expected that there is a strong economic incitement for implementing the suggestions. The costs would be expected to be far less than €6M.

Appendix A1: Defining Area utilization

The purpose of this section is to clearly define the concept of "Area utilization" and provide insight to different possible definitions of the concept.

Possible definitions

As mentioned in the introduction, the initial definition of area utilization was presented:

$$Area\ utilization = \frac{output}{m^2} \tag{1}$$

However, several other definitions are possible and should be discussed. To kick off this discussion, the term "utilization" can be helpful to define:

Utilization: "The extent to which something is put to use for a particular purpose" (w)

[www.wordnet.princeton.edu]

During the course of this project two main perspectives have evolved concerning the definition of *area utilization*

1. *Perspective*

In the first perspective, two options have been found. The question in focus here is merely: "How are the m^2 utilized?" Based on predefined classifications of areas the utilization in GMH2 can be found.

<u>Option A</u>

In 2007/2008 GMH2 investigated the area utilization based on three main categories:

- Production area: The different areas, e.g. machining, or cells, e.g. TP300, was classified as production area, with the exception of the m^2 used for inventory
- Inventory: The inventory in the different production areas, in addition to the entire area of the internal warehouse.
- Major roads: The roads between the areas and cells used by forklifts, etc.

This leads to: *Area utilization = production area vs. inventory vs. major roads* (1a)

<u>Option B</u>

Another possibility is to apply a mindset related to "Value-Stream-Mapping" (VSM).What is in focus here are the m^2 where value adding activities are taking place contra the m^2 where non-value adding activities are taking place. This led to four categories:

- Production equipment and assembly stations (value adding): One overall category including production equipment (including computers and steering closets), assembly-lines, assembly-stations, shop floor used for assembly or packing, test beds and the measuring room. In other words, all the m^2 where an activity takes place that adds value to the product.
- Inventory (non-value adding): Shelves, racks, shop floor and Christmas-trees storing raw components or materials.
- Major roads (non-value adding): The roads between the areas and cells used by forklifts, etc.

- Walking space (non-value adding): The space within the different areas used for operators to move around, room for maintenance, etc.

This leads to: *Area utilization = value adding vs. inventory vs. major roads vs. walking space* (1b)

2. Perspective

In the second perspective, three options have been found. The question in focus here is: “How are the m^2 utilized in relation to the goal and purpose of GMH2?” This leads to another question: what is the purpose of GMH2? There are four options, leading to the following four definitions:

<u>Option A</u>

Goal: Produce pumps; hence $$Area\ utilization = \frac{output}{m^2} \qquad (2a)$$

<u>Option B</u>

Goal: Generate turnover; hence $$Area\ utilization = \frac{turnover}{m^2} \qquad (2b)$$

<u>Option C</u>

Goal: Add value; hence $$Area\ utilization = \frac{Added\ \ value}{m^2} \qquad (2c)$$

<u>Option D</u>

Goal: Generate profit; hence $$Area\ utilization = \frac{profit}{m^2} \qquad (2d)$$

Discussion of perspectives and definitions

When looking into the different perspectives and definition, it becomes clear that there are several possibilities. The purpose of this discussion will be to highlight some strengths and weaknesses of the different definitions.

Looking at ratios

Focusing on (1a) and (1b), in practical use, these would be ratios or percentages (compared to the total m^2 of GMH2). Intuitively, the goal here would be to increase the ratios of “production area” and “production equipment/stations” respectively, and decrease the other ratios. The question is which classification is most appropriate.

Objectively, the value adding activities are not (by definition) taking place in all of the production areas, as (1a) suggests. More accurately, the value adding activities are taking place on the equipment, stations lines and packing areas as (1b) suggests.

(1b) describes area utilization more accurately than (1a), since the focus is value adding m^2 and not merely (predefined) production areas. It can be discussed whether the classifications of (1b) is accurate enough or whether addition categories are needed. It has been discussed several times whether categories such as “needed walking space, room for maintenance”, etc.should be used. However, going back to the mindset of VSM, the question which should be in focus should be “does this m^2 add value – yes or no?”

Analysis 2007 and 2008 showed that there is a remarkable difference depending on which option is chosen (see appendix B2).

Purpose vs. constraint

The second perspective tries to define *area utilization* by looking at the purpose of GMH2 (output, turnover or profit) and how the constraint, the m^2, are used to achieve this. As (w) suggests, it makes sense to include "the purpose" when discussing utilization. Here the m^2 are not divided into different categories, however the total m^2 of the cell or area are applied. No matter which of these three options (2a), (2b) or (2c) is chosen, some errors or shortcomings will present themselves.

The impact of dimensions

If looking at output (2a), most obvious shortcoming, is that GMH2 cannot compare *area utilization* "cross-areas". The difference in dimensions of the pumps (e.g. the 50cmx25cmx25cm TP100-200 vs. the 200cmx75cmx75cm TP400) will affect the *area utilization*. Naturally it is possible to obtain a higher output with less m^2 (a smaller cell) if smaller pumps are produced. On the contrary, several m^2 are required to handle and maneuver the large components and pumps around. For instance, using this definition, the *area utilization* for the TP100-200 will result in the following:

$$Area\ utilization = \frac{output}{m^2} \quad \rightarrow Area\ utilization\ TPs = \frac{52.000\ pcs}{300\ m^2} \rightarrow \underline{\underline{Area\ utilization\ TPs = 173\ pcs/m^2}}$$

Performing the same calculations on the TP400 area, this result will be the following:

$$Area\ utilization = \frac{output}{m^2} \quad \rightarrow\ Area\ utilization\ TP400 = \frac{493\ pcs}{400\ m^2} \rightarrow \underline{\underline{Area\ utilization\ TP400 = 1\ pcs/m^2}}$$

These results can be difficult to interpret. Does this mean that *area utilization* in the TPsmall cell is remarkable better than TP400? It might be the case – it might not. Using this definition (2), *area utilization* is highly influenced by the dimensions of the pump and cannot be compared across different ranges with different dimensions.

Turnover generation

This problem, with the initial definition of *area utilization* (1), was discovered relatively quickly in the course of the study. To overcome this problem, it was decided to define *area utilization* as in (2b), since converting to turnover was expected to compensate for this dimensional difference. The larger pumps are sold for a higher price, compared to the smaller pumps [NHB]. Whether shift from output to turnover compensates accurately has not been thoroughly investigated and can be discussed. However, this definition (2b) leads to another problem.

If looking at TP300, the assembly area constitutes 1000 m^2 and the yearly turnover around € 45,0 mill. Given (2b), the following can be presented:

$$Area\ utilization\ TP300 = \frac{turnover}{m^2} = \frac{45.000.000\ €}{1000\ m^2} \rightarrow \underline{\underline{Area\ utilization\ TP300 = 45.000\ €\ /m^2}}$$

The turnover can be thought of as the total (monetary) value GMH2 receives from producing TP300 pumps. The problem here is that the turnover/value is not generated in the assembly cell alone. Components going into the pumps are being machined and painted as well in the machining area, adding to the total value, and in effect the turnover. To get a more accurate picture the turnover should be "split" into the different areas where it is generated.

Pricing structure and data constraints
This problem led to the definition (2c), where the purpose is to add value to the products. *Added value = output value – input value*. Given this definition, it should be possible to allocate the *added value* to the different areas. However, it is not possible to get this data. The pricing structure of the pumps is not based on a bottom-up approach, where costs and profits are calculated throughout the chain starting from suppliers. However, instead a top-down approach, where the customer price is the starting point and then profits are placed backwards on organizational levels where desired [Finance department]. What this means, is that the routings in SAP does not allow to discover input and output values throughout the chain on area level, e.g. from machining to painting to assembly.

Financial considerations
The definition of (2d) the problem can be described similar to (2b) and (2c). It is not possible to determine the profit of the different areas in GMH2, and actually performing these calculations merely on the assembly areas (even though the profit is generated in the whole chain), yield negative profit margins in some cases; hence unusable results. The allocation of direct and indirect costs simply exceeds the sales. Financial considerations from a Group perspective are expected to be the causes; however this has not been verified.

Outside factors
Another aspect which deserves mentioning is the fact that (2a-d) can be affected by outside factors. Looking from one year to another, sales can be expected to vary. What this implies, is that the *area utilization* for an area can actually drop without any “negative” changes internally. The *area utilization* can therefore be expected to be influenced by factors that GMH2 has no control over.

Summary
As expected, several possible definitions of *area utilization* can be presented. Possibly (and likely) other definitions can be presented if looking from different perspectives e.g. a cost and investment perspective.

Appendix A2: Area Utilization as Performance Measurement

The purpose of the following section is to shortly discuss whether area utilization is an appropriate performance measurement. It is found that non-performance related factors influence area utilization as defined on Group level.

On Group level and in GMH2 it has been decided to define and measure *area utilization* as [JTO, NHB]:

$$Area\,utilization = \frac{turnover}{m^2}$$

At a factory-level perspective for GMH2, this definition seems to make sense. However, as mentioned in appendix A1, when digging a little deeper, the definition has several flaws. Outside factors (drop in demand) and inaccurate allocation of turnover (all turnovers placed in assembly areas) affects the result. In addition it can be debated whether this definitions "favors" smaller pump ranges. This can be viewed as a discussion of *local* vs. *global* optimization.

From a *local* perspective (GMH2) applying this definition might lead to some undesirable results. The following scenarios are likely:

1. Machining of components is not desirable since only assembly areas adds turnover.
2. In terms of new pump ranges, smaller pumps are preferred since they lead to better *area utilization.*
3. Problems with *area utilization* in areas with a high turnover (e.g. TP300) are not receiving attention since other areas with less turnover show poorer results.

The first two scenarios could present a problem from a *global* perspective (Group level). The machining of components is kept in-house to maintain know-how, however new machining centers might be down prioritized and pressure is put to have assembly production instead. With respect to new pump ranges, synergies between some of the larger pump ranges might be missed. Applying this definition of *area utilization* could give local incitement to push pump ranges (or component production) away which in effect might have a negative result globally. In addition the third scenario indicates that real problems are hidden in high-turnover areas contra low/medium-turnover areas.

It can be argued, that if a range has a low turnover, and it can be substituted with a range with a higher turnover, maybe this should be the case? However, this is a strategic decision and currently the Group wishes to have a complete product portfolio. This adds to inappropriateness of the current definition.

However, the definition does seem to have a place and a justification. If viewing, merely as a measurement (a status), it can be used when discussing change-initiatives. If a e.g. lean or JIT initiative is expected to free x m^2, this definition can assist in persuading the decision-makers, budget approvers, etc. The power of the definition is the fact that a monetary value (a language managers and board-member speak) is connected with m^2. The definition is useful as a measurement within <u>one</u> area if comparing as-is and to-be scenarios. When it is used in a wider sense, the definition is affected by factors not relating to area utilization and can be expected to provide false or inaccurate information.

Summary

It can dangerous to use *Area utilization* as a performance measurement since factors, such as pump dimensions, affect the result. For argumentation purposes both turnover share, profit share and investment share can be useful, but if applied as performance measurements sub optimization might be the outcome and from a global perspective this could yield undesirable.

Appendix B1: Area Utilization Analysis

The purpose of this section is to describe the process of measuring the area utilization. Two analyses have been conducted and approaches and results will be described.

Analysis 2007: Rough plant view

GMH2 performed an analysis of the area utilization in the fourth quarter of 2007 and the first quarter of 2008. The analysis was approached by using three categories. The following classifications were used:

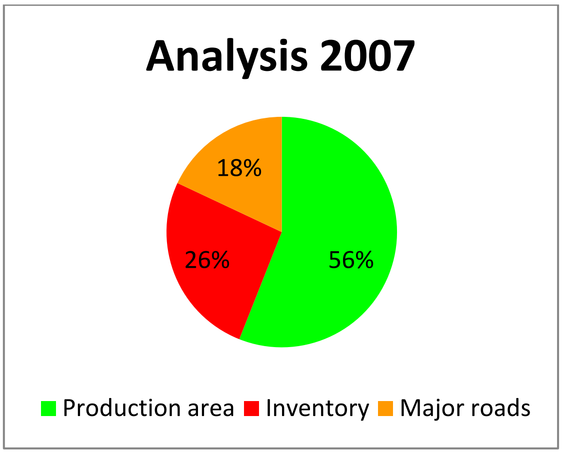
- **Production area**: The different areas (e.g. machining) or cells (e.g. TP300) was classified with the exception of the m^2 used for inventory
- **Inventory**: The inventory in the different production areas, in addition to the entire area of the internal warehouse.
- **Major roads**: The roads between the areas and cells used by forklifts, etc.

The measurements were conducted in AutoCad were layouts of GMH2 are accessible. This also implies that a minimum of manual measurements were conducted. The results of this analysis will be referred to as "Analysis 2007".

Analysis 2007: Rough plant view [m^2]				
	Production area	**Inventory**	**Major roads**	**Total area**
NK	600	0	N/A	600
NB	410	140	N/A	550
TP100-200	220	80	N/A	300
TP300	680	320	N/A	1.000
TP400	400	0	N/A	400
WW	600	150	N/A	750
Spare parts	200	0	N/A	200
Machining	1.650	350	N/A	2.000
Impeller cell	250	50	N/A	300
Painting	900	150	N/A	1.050
Warehouse 1 (incoming)	0	1.500	N/A	1.500
Warehouse 2 (Packing)	0	300	N/A	300
Warehouse 3 (Additional)	0	100	N/A	100
Finished goods area	450	N/A	N/A	450
Packing area	300	N/A	N/A	300
Major roads	0	0	2.200	2.200
Total GMH2:	**6660**	**3140**	**2200**	**12.000**

Table 14: Overview of Analysis 2007

The results presented in table 14, can be depicted as a pie diagram, showing the ratios between the different categories.



Picture 11: Results of analysis 2007 depicted as graph

Analysis 2008: Detailed area view

The author of this report conducted a similar analysis in the third quarter of 2008. The analysis was approached using four categories. The following classifications were used:

- **Production equipment and assembly stations** (value adding): One overall category including production equipment (including computers and steering closets), assembly lines, assembly stations, shop floor used for assembly or packing, test beds and the measuring room. In other words, all the m^2 where an activity takes place that adds value for the customer (see “Customer value”)
- **Inventory** (non-value adding): Shelves, racks, shop floor and Christmas-trees storing raw components or materials.
- **Major roads** (non-value adding): The roads between the areas and cells used by forklifts, etc.
- **Walking space** (non-value adding): The space within the different areas used for operators to move around, room for maintenance, etc.

The measurements were conducted manually. The layouts from AutoCad were used as “backbone” and observations and measurements were performed in GMH2. Where possible and where the reality matched the AutoCad drawings, AutoCad were used for measuring. In the following, the results of this analysis will be referred to as “Analysis 2008”.

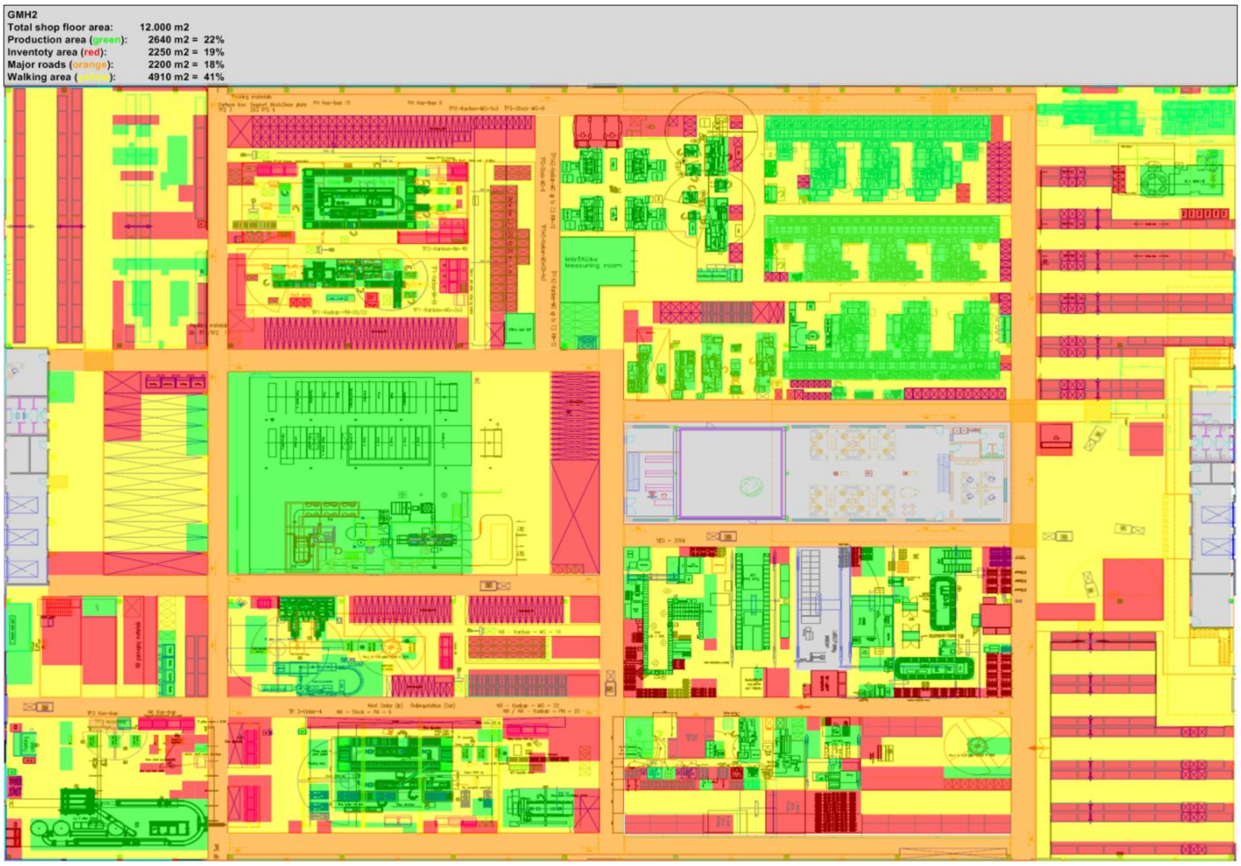


Figure 35: Map of GMH2. The result of Analysis 2008 with the selected categories.

Analysis 2008: Detailed area view [m^2]				
	Equip. & ass. stations	**Inventory**	**Major roads**	**Work/ walk space**
NK	195	160	N/A	245
NB	85	225	N/A	240
TP100-200	75	75	N/A	150
TP300	155	390	N/A	455
TP400	150	40	N/A	210
WW	270	150	N/A	330
Spare parts	20	65	N/A	115
Machining	900	200	N/A	900
Impeller cell	70	100	N/A	130
Painting	650	140	N/A	260
Warehouse 1 (incoming)	0	510	N/A	990
Warehouse 2 (Packing)	0	130	N/A	170
Warehouse 3 (Additional)	0	65	N/A	35
Finished goods area	20	0	N/A	430
Packing area	50	0	N/A	250
Major roads	0	0	2200	
Total GMH2:	**2640**	**2250**	**2200**	**4910**

Table 15: Overview of Analysis 2008

The results presented in table 15, can be depicted as a pie diagram, showing the ratios between the different categories.

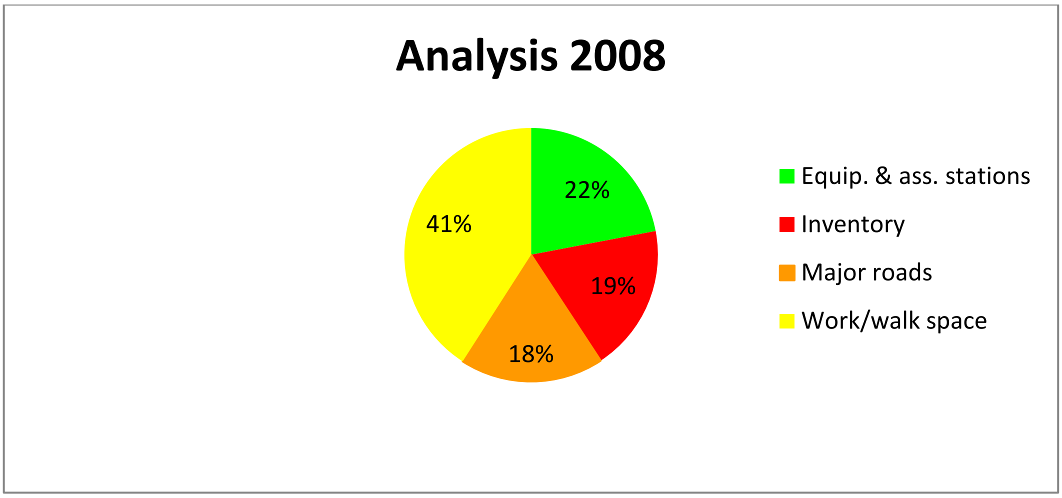


Figure 36: The results of analysis 2008 as pie-diagram

Turnover and output

In addition to the ratios between the different categories of m^2, the turnover-share (*area utilization* as defined by GMH2 (2b)) and output-share (2a) have been analyzed. The turnover and output is based on Q3 and Q4 in 2007 and Q1 and Q2 in 2008. Table 16 shows the results:

Turnover and output-share in GMH2					
Area	**Turnover [M€]**	**Output [pcs.]**	**m^2**	**Turnover/m^2[€/m2]**	**Output/m^2**
GMH2 Total*	**117,0**	**173.272**	**12.000**	**9.750**	**14**
TP100-200**	**14,6**	**52.282**	**289**	**50.400**	**181**
TP 300	**45**	**49.369**	**973**	**46.300**	**51**
TP 400	**2,93**	**514**	**387**	**7.600**	**1**
NB	**17,4**	**22.248**	**519**	**33.500**	**43**
NK/TPM	**8,8**	**8.152**	**580**	**15.250**	**14**
WW + DW	**23,1**	**40.707**	**754**	**30.600**	**54**
Mach. Dep. Total***		**283.266**	**2.006**		**141**
Pump housing		81.906	921		**89**
Motor stool/cover		60.213	213		**283**
Imp./m-stool/cover		22.212	102		**218**
Impeller		86.166	170		**507**
Cover/oil chamber		19.297	104		**186**
Flanges SE		13.472	52		**259**
Painting Total		**283.266**	**1.023**		**277**

Table 16: Turnover share (area utilization) and output-share in GMH2

The turnover-share of the different assembly areas can be depicted in a block diagram. Fig. 37 shows the diagram

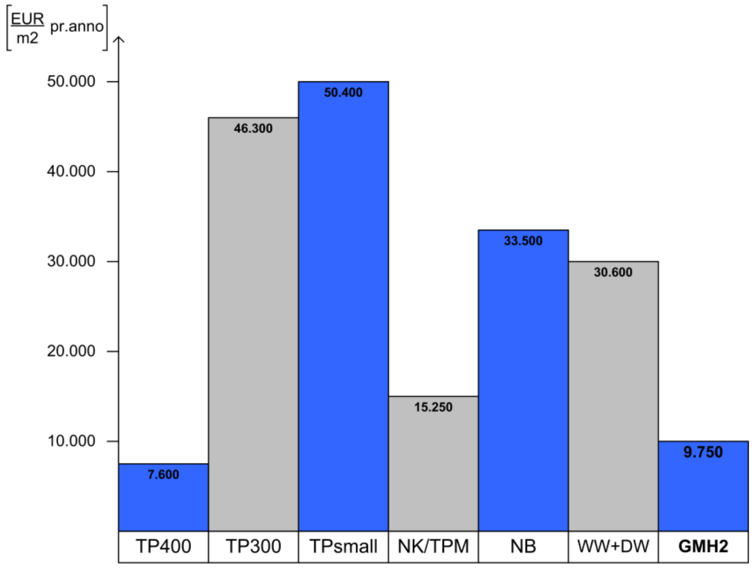
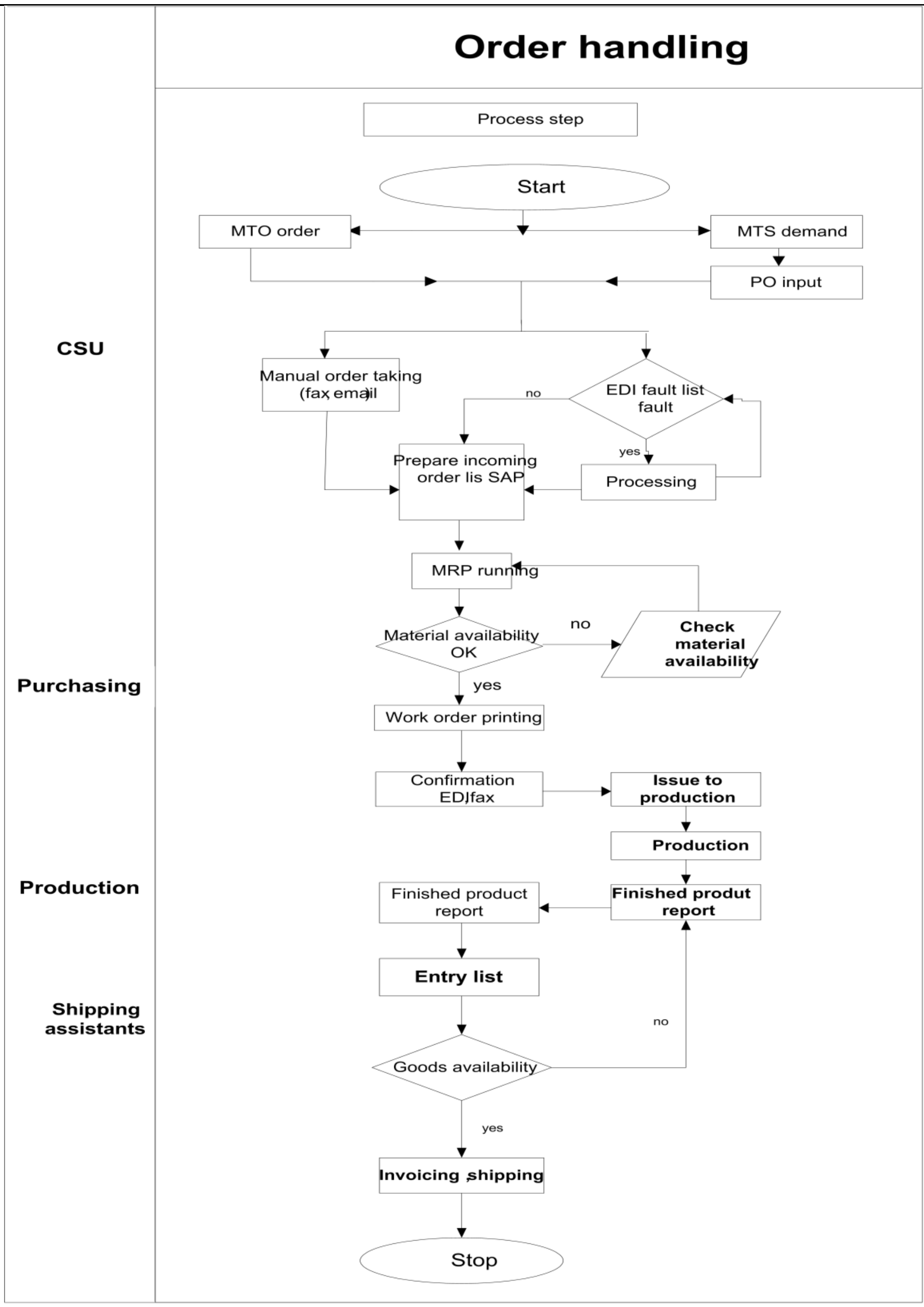


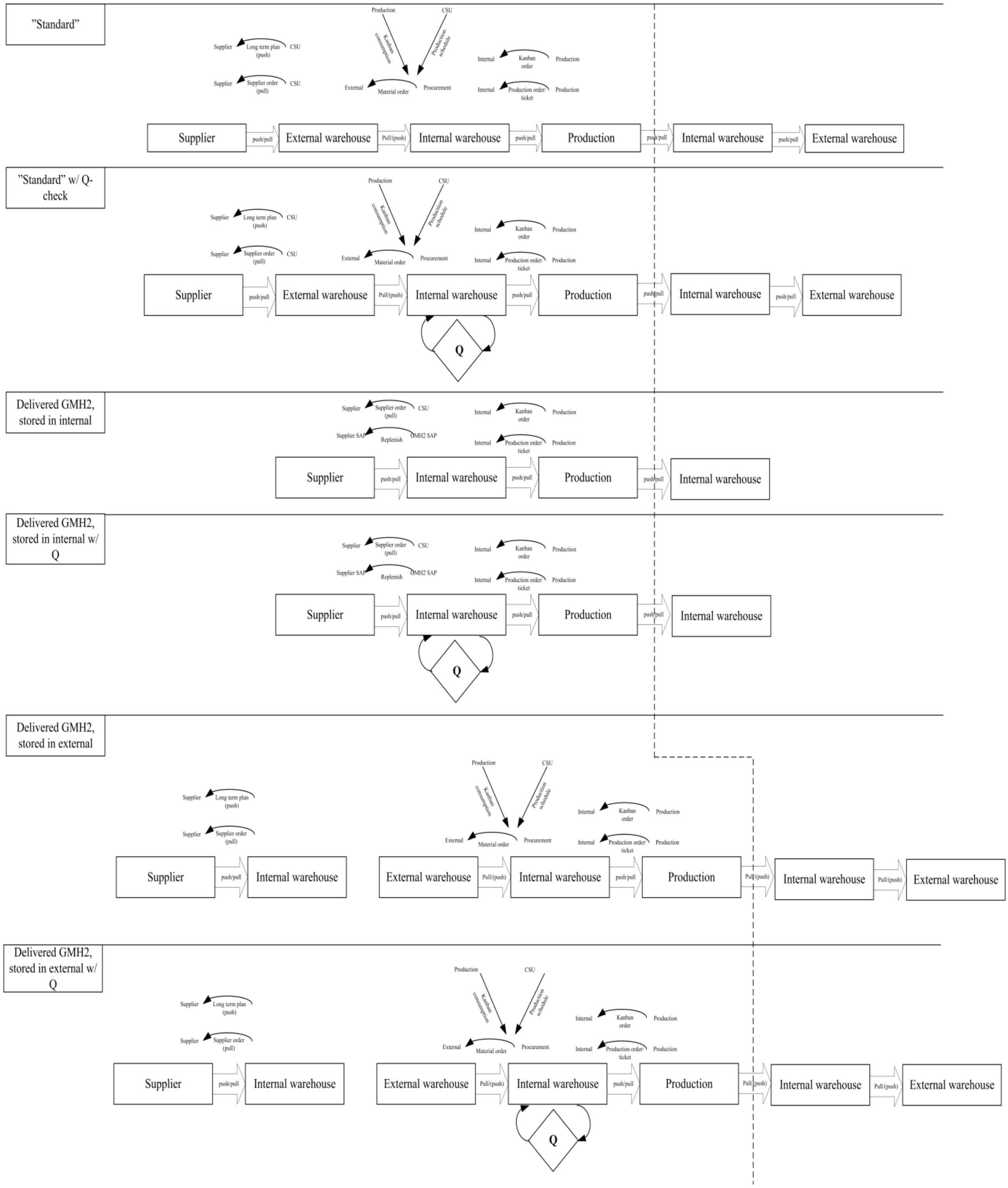
Figure 37: The area utilization divided into the different assembly areas

Appendix B2: Overview/comparison of Analysis 2007 and Analysis 2008

Appendix C: Order handling flow GMH2



Appendix D: Material and information flow for incoming goods in GMH2



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MC, Miklos Csatay, Lead PE engineer GMH2

NHB, Niels Henrik Boldvig, Process Manager GMH2

ZBA, Zoltán Balogh, Production Manager GMH2

ZFA, Zoltán Farkas, Production Area Manager GMH2

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Insite – Grundfos intranet

Lotus note database

G-drive: Common server drive in GMH

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Figures

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