Effects on logistics when fluctuations in production occur

A case study on forklift operations at Autoliv Vårgårda

Master of Science Thesis in the Master Degree Program Supply Chain Management

DANIEL ANDERSSON

PETER GRANBERG

Department of Technology Management and Economics
Division of Logistics and Transportation
CHALMERS UNIVERSITY OF TECHNOLOGY
Göteborg, Sweden, 2011
Report No. E2011:088

REPORT NO. E2011:088

Effects on logistics when fluctuations in production occur

A case study on forklift operations at Autoliv Vårgårda

DANIEL ANDERSSON

PETER GRANBERG

Department of Technology Management and Economics
Division of Logistics and Transportation
CHALMERS UNIVERSITY OF TECHNOLOGY
Göteborg, Sweden, 2011

Effects on Logistics when fluctuations in production occur
A case study on forklift operations at Autoliv Vårgårda

Report No. E2011:088
Department of Technology Management and Economics
Chalmers University of Technology
SE-412 96 Göteborg
Sweden
Telephone +46 (0)31-772 1000

Chalmers Reproservice
Göteborg, Sweden 2011

ACKNOWLEDGEMENTS

This thesis is a summary of the key aspects from our work at Autoliv Sweden AB during January to June 2011. During this period we gained valuable insight in how internal material handling is organized, while at the same time got to meet and know proficient and extraordinary people. Considering that Autoliv won the lean award in 2010, it has been extra rewarding for us to follow, and hopefully contribute to, their continued lean journey.

We would like to thank Autoliv Sweden AB for giving us the opportunity enabling this master thesis. During the thesis, all employees at Autoliv and especially the ones at the logistics department have been very helpful and their input to our thesis is much appreciated. Furthermore, we would like to thank Erik Tönsgård, former group manager supply chain development, for helping us getting started and Catrin Simonson, supply chain engineer, for her supervision and guidance during the thesis.

In addition, we would like to take the opportunity to thank PhD Carl Wänstrom and PhD student Christian Finsgård, department of Logistics and Transportation at Chalmers University of Technology, for their input and perspectives on our thesis topic. Finally, we owe our gratitude towards Martin Svanberg, our academic supervisor, for his guidance which essentially made this thesis a memorable and rewarding experience.

Gothenburg June 2011

Daniel Andersson and Peter Granberg

ABSTRACT

Through concepts like lean production and supply chain management, material flows and waste reduction, for and in between activities and organizations, has become of increasing concern for managers. Production and logistics is closely related to each other with logistics traditionally supportive and subordinate, however this is changing when inter organizational aspects are more and more addressed. To identify how production affects logistics is essential in order to understand why and how internal logistics workload fluctuates and causes problems when dimensioning and planning. The purpose is therefore to:

"…to analyze how the internal logistics function is affected by fluctuations from the leveled production schedule through a case study at Autoliv Vårgårda. In what way these fluctuations affect the internal logistics function is simulated in an excel model. Through relating a normative fully leveled state to different scenarios reflecting fluctuations in production."

At the case company, aspects and contemporary conditions are identified and summarized in an Excel model. The model is used to evaluate and analyze representative scenarios in order to match the purpose. The scenarios are a representation of how production affects logistics at Autoliv. An analysis from Autoliv's perspective, the scenarios and the theoretical view are used for the analysis.

The logistics function at the case company is affected by fluctuations from the planned production schedule in several ways. The product characteristics, mismatch between takt and production gears, managerial decisions and work queuing all shown to have significant impact and yielded unpredictable and erratic demand for logistics workload. In academic terms, the fluctuations in production are found to impose unevenness in workload and at times overburdening the forklifts operators. Consequently, proper constraints how production is allowed to deviate from the leveled production schedule and lack of information transfer between production and logistics is introducing *mura* and *muri* for the internal logistics function.

TABLE OF CONTENT

LIST OF FIGURES

LIST OF TABLES

LIST OF ABBREVIATIONS

Abhall	Forklift operator in production Hall A and B
AMG	Autonomous Manufacturing Group
AMT	Autonomous Manufacturing Team
BOM	Bill-of-Material
Chall	Forklift operator in production Hall C
CPR	Capacity Requirements Planning
DAB	Drivers Airbag
DCU	Driver Central Unit
EOP	End of Production
ERP	Enterprise Resource Planning
FGS	Finished Goods Storage
IC	Inflatable Curtain
JIT	Just-In-Time
MPS	Master Production Scheduling
MRP	Material Requirements Planning
PAB	Passenger Airbag
RC	Receiving Center
R&D	Research and Development
SAB	Side Airbag
SCM	Supply Chain Management
SM1P	Forklift operator in cell SM1 Packing
SM23	Forklift operator in cell SM2 and SM3
SM4	Forklift operator in cell SM4
SOP	Sales and Order Planning
TPS	Toyota Production System
USM1	Forklift operator in cell Upper SM1

1. INTRODUCTION

Chapter one introduces the reader to the thesis topic and motivates its academic relevance. The issues highlighted through the background are then used as a base for the problem analysis, which discuss the topic more in-depth, leading to the purpose and thereby establish the explicit objective this master's thesis aim at addressing. Finally, chapter one ends with scope and limitations and a brief reading guide.

1.1. Background

During the last 50 years a fundamental transition in the business environment has occurred; a shift from being the producer's market towards being the buyer's market (Ivanov & Sokolov, 2010). Thus, firms gradually needed to adapt to changing conditions to be competitive. In order to reduce manufacturing cost, produced volumes could no longer be matched with customer orders since scale gains would be lost (Johansson & Johansson, 2006). A different mindset emerged and companies started to focus on the value for customers through a concept named *the value chain*. This in turn lead to a need to coordinate the different actors and processes within the value chain, a concept called *Supply Chain Management* (SCM) (Skjoett-Larsen et al., 2007). Internal and external logistics have thus emerged as a focus area for managers.

An all-encompassing approach towards logistics and production is found within Japanese production philosophies made famous by Toyota. In the 1980's the world recognized Toyota's superior product quality and production efficiency (Liker & Meier, 2006). What made Toyota so successful? With scarce resources and little demand, large batch production could not be supported for reasons of liquidity (Liker & Meier, 2006). These conditions inevitably forced Toyota to focus on value adding and reducing wasteful activities (*muda*) to free resources. Not only non-value adding activities are wasteful, so are also unevenness in workload (*mura*) and overburdening of people (*muri*). The identified categories of waste, is today the foundation of several fundamental principles within the Toyota production system (*commonly: lean production*). *Just-in-time* (JIT), in-station-quality (*jidoka*) and leveled scheduling (*heijunka*) are all examples to on how to minimize waste. In essence, Toyota not only managed to identify wasteful activities but they also addressed the timing of activities. There is no value in performing activities prior to the immediate needs; however there is a value in smoothing (leveling) out activities over time to reduce erratic demand behavior.

Erratic demand behavior is often called the bullwhip effect (Skjoett-Larsen et al., 2007). Commonly, research addresses the bullwhip effect between companies, however some research suggests the bullwhip effect exists also within the firm; namely between inbound and outbound logistics flows (Svensson, 2003). Thus, the internal logistics function, handling all transportation between the inbound and outbound nodes, is under the effect of the internal bullwhip effect. In addition, manufacturing firms' production largely determines logistics performance, while material managers tend to focus on keeping trucks full rather than delivering parts right on- time, quantity and presentation to production(Baudin, 2004). Therefore, to address this erratic demand behavior, resulting in unevenness in workload and overburdening operators at times, and to mitigate the bullwhip effect, leveled production scheduling is proven to be successful(Liker, 2004).

1.2. Problem analysis

Leveled scheduling aggregates volumes over time and efficiently even out downstream demand, safeguard upstream tiers against demand peaks and compel production to shorten set up times (Baudin, 2004; Liker, 2004). This creates a predictable environment for production and support functions, resource utilization is leveled and the risk of overproduction and overburdening is mitigated. Through leveled scheduling production becomes a solid foundation for improvements and production efficiency. Utilizing a leveled schedule, in both volume and product mix, will put pressure on production to shorten set-up times and reduce batch sizes. However, at the same time, it transforms production into a more flexible system, with higher potential to respond to changes in demand. Support functions such as internal logistics is highly dependent on production. Internal logistics, located between the uncertainty of the distribution and supplier networks, while at the same time subordinated to production, is therefore subject to any variation or fluctuation arising in either three.

Leveling the production schedule evens out resource demand and will essentially takt production. There are reasons why the leveled schedule may not be possible to accomplish or match in reality; number of variants on a production unit in combination with unfeasible set up times makes it inefficient, actual customer demand is different from the aggregated volume or the productive unit is unable to match the overall takt time determined by the leveled schedule. Furthermore, common production disturbances such as quality issues, machine malfunctions, material shortage and human factors increase the probability for deviations from the production schedule. The mismatch between plan and reality will impose variation on adjacent functions and more precise the logistics function.

In addition, there are reasons for disregarding a leveled production on the operative level. Some reasons for fluctuations are traced back to production efficiency measures and some are related to disturbances occurring in reality, which cannot completely be erased, merely diminished. Re-arranging operators, by that changing the takt, between production cells will distort the planned material flow and logistics work become irregular.

From a lean perspective, the truly leveled schedule should be used regardless if there are shortsighted efficiency gains in production. The logistics function is directly adjacent to production and sub-ordinate production in priority. It is therefore interesting to see how the logistics function is affected by fluctuations in production. Furthermore, it is interesting to examine effects on the internal logistics function, when decisions made in reality mean deviating from the production schedule, to be able to relate how decisions in production affects logistics.

1.3. Purpose

The purpose of the thesis is to analyze how the internal logistics function is affected by fluctuations from the leveled production schedule through a case study at Autoliv Vårgårda. In what way these fluctuations affect the internal logistics function is simulated in an excel model. Through relating a normative fully leveled state to different scenarios reflecting fluctuations in production.

1.4. Scope and limitations

To determine how fluctuations in production will affect internal logistics, a model for calculating transportation demand, generated by the takt time for each production cell, is created. The model will account for series production and determine the number of pallet movements required to produce a product for the production cells. The overall transportation demand is then found through aggregating all production cells' planned output from contracted volumes and takt times. The amount of transport work is broken down to each forklift operator handling the material flow in order to measure production's fluctuation impact on specific operator.

However, all activities and forklift operators within the material flow department is not subject to the analysis. In order to delimit the analysis only to activities adjacent to the production cells, logistics activities directly connected to the production cell is regarded. In addition, tow cart trains are not considered as logistics activities since they are organizationally located under production. Thus, only the forklifts handling the in- and outbound flows to the production cells are included. Reserve products are handled separately which is why only the production cells in series production is included.

1.5. Outline

In this section a brief reading guide to facilitate reading the report is presented. An overview of the report layout is presented in Figure 1.

Introduction	**Theoretical framework**	**Methodology**	**Case company - Autoliv**	**Analysis**	**Discussion**	**Conclusions**	**Recommendations to Autoliv**
Background	Supply chain managment	Case study		The excel model	Method	Concluding remark	Develop the model
Problem analysis	Lean production	Information collection	Case specific information	Scenario presentation	Error sources	Academic contribution	
Scope and limitations	Material planning & control	Analysis	Production activities	Scenario analysis	Solutions	Future research	Restriction to Rail management
Outline	Material handling	Validity		Results			Information sharing
Chapter 1	Chapter 2	Chapter 3	Chapter 4	Chapter 5	Chapter 6	Chapter 7	Chapter 8

Figure 1: Report layout including all chapters.

Chapter 1 and 2 presents the topic and establish the purpose and contribute with an academic framework in relation to the topic. All readers are encouraged to read these chapters, however chapter 2 may be skipped by persons with knowledge within the topic area. Chapter 3 covers the methodology and all readers are urged to read the analysis methods part. The fourth chapter deals with the information regarding the case company. For Autoliv employees, the case specific section can be skipped and the other two sections are relevant for all readers to increase readability. The analysis and discussion is recommended in order to be able to relate the conclusions, findings and recommendations to the topic. For readers seeking a quick results overview, the two most right chapters is recommended, where conclusions and recommendations to Autoliv is discussed.

2. THEORETICAL FRAMEWORK

This chapter provides a theoretical context for the thesis, hence theory required to understand the method, analysis and results are included. Research areas, concepts, subjects and sub-theories is presented in a brief manner and the reader is encourage to seek within the source material if more elaboration is preferred. Theory in direct relation to each other is reviewed together where applicable, however, for reasons of readability this is not always possible. The holistic context is supply chain management, which is why the chapter begins with a short introduction to the area defining the concept in relation to production and logistics. In recent years, and at the case company, lean production is an important source of inspiration and consequently lean production and a few key concepts are presented. Having established the overall context, material planning and control together with material handling completes the context in which the thesis is situated.

2.1. Supply chain management

SCM coordinates supply, production and distribution, which makes other strategic objectives possible (Skjoett-Larsen, et al., 2007). The supply chain- and supply management concepts are wide and consequently the boundaries are vague (Mentzer, et al., 2001). Furthermore, in addition to coordinating supply, production and distribution, Mentzer, et al (2001) include *Research & Development* (R&D), information systems, customer service and finance and ultimately the coordination from raw materials to end customer. Owing to the industry shift from single organizational optimization to inter-organizational coordination, SCM emerged to fill the gap existing between organizations (Skjoett-Larsen, et al., 2007). In addition, to coordinate efficiently, information transfer is essential and the past years development within information technology has further supported the deployment of SCM.

Customer demand is often erratic and distorted in the supply chain and depending on placement along the stream; demand amplification will impose problems to coordinate efficiently (Skjoett-Larsen, et al., 2007). The effect is called the bullwhip effect and is perceived both inter- and intra-organizationally (Svensson, 2003). Furthermore, the bullwhip amplifies as it propagates upstream in the supply chain (Liker, 2004). Information sharing or reducing demand distortion can efficiently reduce the bullwhip effect (Skjoett-Larsen, et al., 2007).

For the individual manufacturing firm in a primitive supply chain, the relations to suppliers, customers and logistics are shown in Figure 2. Production and logistics are, from a lean perspective, more detailed defined in the two following sections.

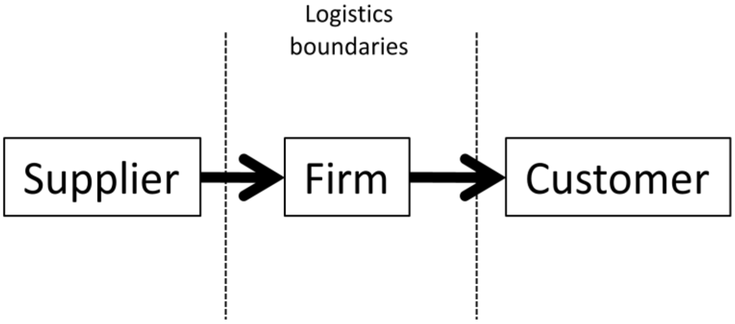


Figure 2: Illustration of a supply chain and how it relates to logistics (Skjoett-Larsen, et al., 2007).

2.2. Lean production

Lean production seeks to improve quality and productivity and originates from Toyota's philosophy on operations management, *Toyota production system* (TPS) (Skjoett-Larsen, et al., 2007). Through continuously striving to develop standardized tasks and process, the lean philosophy is successfully used to eliminate waste (Liker, 2004). During the last decades, lean production have evolved and today offers management principles for all departments within the modern enterprise, however focus are mainly on operations (Schonberger, 2007). In 2004, Jeffrey Liker published his book the Toyota way which presented 14 management principles addressing how to be lean. The management principles within lean production, here by Toyota, are shown in Figure 3.

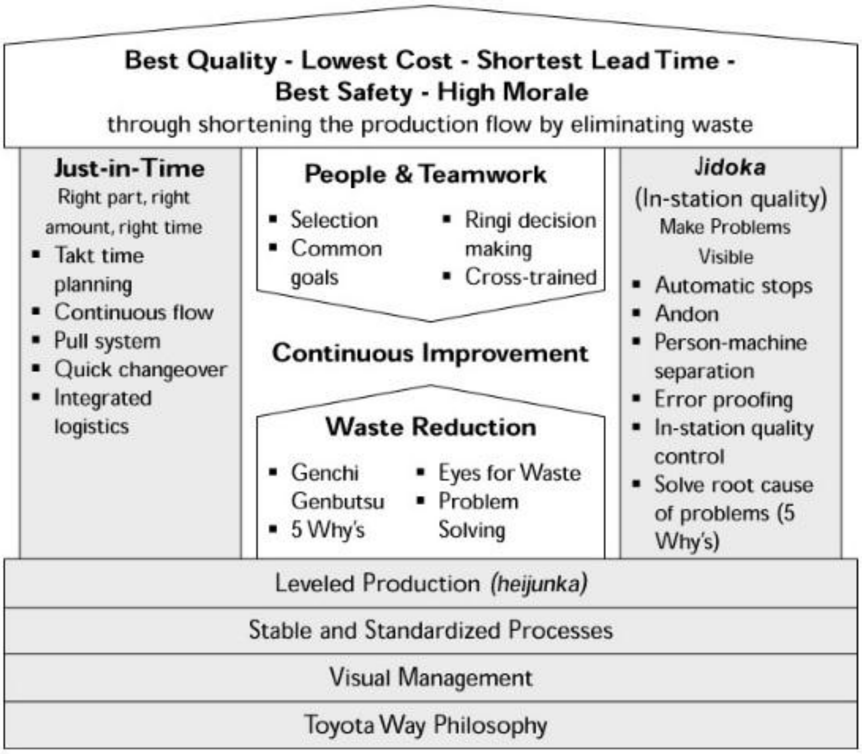


Figure 3: The Toyota production system, visualizing lean production (Liker, 2004).

Best quality, lowest cost, shortest lead time, best safety and high morale is achieved through shortening the production flow by elimination waste. Waste in categorized in three types: *muda* (wasteful activities), *muri* (overburdening people) and *mura* (unevenness in workload) (Liker, 2004). Equal importance to all principles is essential for success. However, a more in-depth description of all principles are not in the scope of this thesis, which is why focus is on lean principles applied in production and logistics at the case company rather than on the overall philosophy level.

2.2.1. Logistics

Logistics is essential for Just-in-time to work and to make material flow (Liker, 2004). Figure 2 show how logistics relate to the supply chain and the logistics boundaries are present for each individual firm throughout the supply chain. The logistics boundaries include external (between firms) and internal logistics (within the firm); however in this thesis focus is on internal logistics, which is why external logistics, is neglected from hereby.

The internal logistics function, to transport materials between locations within a production facility, contains a diversity of flows between locations (Baudin, 2004). Therefore, internal logistics can be resource consuming and thus in focus for rationalization through continuous improvements or major streamlining projects. The internal logistics setup is widely dependent on the site characteristics and industry the firm is operating in(Baudin, 2004). It is therefore likely that the internal logistics function at one site may not be the most efficient choice at another site: a tailored choice is required to maximize performance.

Internal logistics encompass material flows, information flows and funds flows in contrast to production which transforms material through processing or assembly. Furthermore, logistics performance is largely dependent on what happens in production (Baudin, 2004). Unevenness in production output, distortion among work required or non-standardized flows will consequently negatively affect logistics. The bullwhip effect, earlier established also as an intra-organizational effect, will impose unevenness for logistics and thus introduce waste.

2.2.2. Production

Production, the lean way, consumes minimal resources and manufacture products just-in-time in the right amount at the right time (Liker, 2004). Continuous flow, facilitated by quick change over times and integrated logistics, ensures reliable production takt and fast quality feedback (Baudin, 2002). In station quality is essential and each process, operator or balance ensures quality for the products they send downstream (Liker, 2004). Organizing production according to the lean principle, e.g. in a flow cell, will reduce waste by removing wasteful activities, level the workload (*heijunka*) and thus not overburdening people (Baudin, 2002).

2.2.3. Heijunka

Leveled production, or a leveled production schedule, seeks to maintain a leveled production schedule despite erratic customer demand (Jonsson & Mattsson, 2009). In Toyota Production System, leveled production is one of the 14 management principle and it is called *heijunka* (Liker, 2004).

"Heijunka is the leveling of production by both volume and product mix. It does not build products according to the actual flow of customer orders, which can swing up and down widely, but takes the total volume of orders in a period and levels them out so the same amount and ix are being made each day."(Liker, p 166, 2004)

Thus, leveling production smoothens out the mix and volume of items and reduces variation between days, which is better than producing according to the fluctuating actual demand. In practice, orders are from a time period is aggregated and volumes are evenly distributed (Jonsson & Mattsson, 2009). In addition, Liker (2004) includes product mix within his definition, else resources might be unevenly distributed over time and wrong products may be in stock. Customer demand tends to be irregular and there is a risk wrong products are in stock, which leads to lost sales. To hamper this, large inventories could be used, which is costly. Similar products may also draw uneven resources and a leveled schedule helps even resource consumption out.

Leveling the product mix puts pressure on short changeover times (Liker, 2004). Furthermore, having short changeover times facilitates high flexibility, which increases responsiveness towards fluctuations in demand and risk of unsold goods is mitigated. However, efficient changeover may be impossible due to minimal batch sizes, load units, sub-optimized line balancing or too many picking errors in the assembly cell (Baudin, 2002). Leveling the production schedule by product and mix will balance machine use and labor, not only for the particular activity, but also for upstream activities within the company or to suppliers. Consequently, leveling the schedule will facilitate planning other activities such as support functions. Thus, costly adjustments, for all activities within the value stream, such as overtime, sub-contracting and underemployment can be avoided (Jonsson & Mattsson, 2009).

Through its many benefits, leveling the schedule will mitigate the bullwhip effect and together with small inventories form suitable conditions for a pull system (Baudin, 2002; Baudin, 2004).

2.3. Manufacturing planning and control

The manufacturing firm is required to coordinate material and resource flows, else their operations risk being inefficient and in the end unprofitable. Manufacturing planning and control achieve coordination through planning, control and follow-up (Jonsson & Mattsson, 2009). In addition to coordination, Jonsson and Mattsson (2009) credit manufacturing planning and control to comprise development, organization and management of material flows from suppliers to end users. Vollmann et al, (2005) also express the importance of balance between supply and demand; imbalances between supply and demand will lead to inefficiencies. Typically the demand is not compatibly directly with the supply, which means that the gap between supply and demand needs to be bridged. This can be done either by forecasting or postponement (Gadde, 2004). When postponment is impossible, e.g. the time frame of producing the demanded goods is longer than the customer is willing to wait, a forecasting method must be used. The scope of forecasting may concern decision making on every level of planning in a company. However, in the context of manufacturing planning and control, forecasting is mainly an assessment of future demand for the company’s products (Jonsson & Mattsson, 2009).It is therefore very important to coordinate the manufacturing with marketing and sales as well as other functions.

In Figure 4, the scope and concepts within manufacturing planning and control, according to Jonsson and Mattsson (2009) are schematically presented vertically by level in the planning hierarchy, degree of detail and time horizon while horizontally separating between the material and capacity perspectives. The hierarchy contains three main levels; *Sales and operations planning* (SOP), *Master production scheduling* (MPS) and order planning. The fourth, and bottom level, is the execution of the main hierarchy levels.

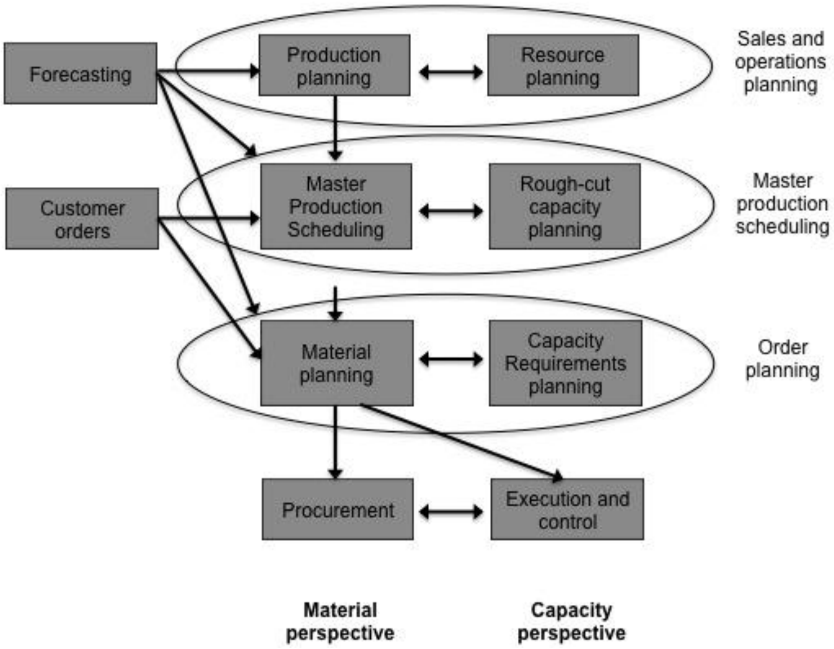


Figure 4: Overview of the different planning levels from the materials and capacity perspective (Jonsson & Mattsson, p.38, 2009).

Sales and operations planning, in a firm, link strategic goals to production plans and are thus integrating marketing, finance, operations and planning of resources into a cross-functional plan to increase success in its markets (Vollmann et al., 2005). Consequently, it is the most aggregate planning level with the longest time horizon and is therefore also the most inexact, illustrated in Table 1. Typically the scope of planning is set on plant level and the top management is highly involved in this part of the planning structure. Subordinate to the SOP is the master production scheduling, which, richer in detail and narrow in planning time horizon, includes setting a rough-cut capacity plan together with a master production schedule. The major reason with MPS is to disaggregate the plan set in the SOP to volumes for specific products. The order planning ensures that procurement and execution and control are coordinated so right materials are available when production including needed material is planned to be executed (Jonsson & Mattsson, 2009). The process and characteristics of order planning is further outlined in 2.4 Order planning.

Table 1: Planning levels and their characteristics (Jonsson & Mattsson, p.33, 2009).

Planning level	Planning object	Horizon	Period length	Rescheduling
Sales and Operations Planning	Product group Product	1-2 years	Quarter/month	Quarterly/monthly
Master Production Scheduling	Product	0,5-1 year	Month/week	Monthly/weekly
Order Planning	Item	1-6 months	Week/day	Weekly/daily
Execution and control	Operation	1-4 weeks	Day/hour	Daily

The bottom process illustrated in Figure 4 is execution and control and its characteristics differ significantly whether the company is using a pull or push system. In a pull system, the order planning process is integrated and pulls material through the execution and control process. Traditional obstacles in production control are mitigated by the pull system. For instance, a pull system generates demand for the precedent workstations without involvement from a central planning system and therefore production orders are redundant. The prerequisites for utilizing a pull system in production are short set-up times, small batch sizes, flow-oriented layout and leveled production (Liker, 2004). A flow-oriented layout is important, so it is ensured that the system of workstations is linked in a synchronized way. The last requirement, leveled production, ensures that a smooth flow is maintained (Jonsson & Mattsson, 2009).

2.4. Order planning

The order planning level ensures that all material required to perform the subsequent activity is supplied on time so no stoppages occur; either internal or external deliveries, like *material requirements planning* (MRP). Order planning also comprises planning capacity requirements on the operative level, like *capacity requirements planning* (CPR). As illustrated in Table 1, the horizon of order planning is typically 1-6 months and is set and rescheduled on a weekly/daily basis. The objective of order planning is to match the supply according to the demand on the operative level. For example by placing new purchase orders or annulling excessive orders to meet changes in demand.

2.4.1. Capacity Planning

In a manufacturing company value is created by a manufacturing operation, refining raw material and components into products. All production operation requires resources, and to which extent these resources can produce a finite volume is called capacity. To be able to ensure production efficiency, a balance between capacity-supply and capacity-requirement is needed, thus capacity planning is needed (Jonsson & Mattson, 2009).

One managerial problem is to coordinate production plans with production capacity. Plans could be matched by adjusting the capacity to fit production plans or by adjusting the production plans to match available capacity. Which method that is preferable depends on the planning level. The second managerial problem is the trade-off between fast throughput times and capacity utilization. In order optimize throughput times a JIT production system is needed, which typically lead to underutilization for some resources (Vollman et al., 2005). To optimize the trade-off between the managerial problems, capacity planning methods corresponding to each of the planning levels is needed.

The master production schedule is validated and altered to fit available capacity, called rough-cut capacity planning. There is also a capacity planning method corresponding to order planning which is set in a more detailed level, CPR. The capacity requirements per product are compiled in a bill, called a capacity bill, including production and logistic resource allocation. On all the above levels coordination to meet the constraints from both the capacity plan and the material plan is needed (Vollman et al., 2005).

2.4.2. Material planning

Material planning is performed differently depending on how material movement is initiated:

"Material planning is of the pull type if manufacturing and material movement only takes place on the imitative of and authorized by the consuming unit in the flow of materials (Jonsson & Mattson, p209, 2009).

Material planning is of the push type if manufacturing and materials movement takes place without the consuming unit authorizing the activities, i.e. they have been initiated by the supplying unit itself or by a central planning unit in the form of plans or direct orders" (Jonsson & Mattson, p209, 2009).

The essential difference between push and pull are how the signal for the operation is initiated. If the initiative is taken centrally, by direct orders or by the unit itself, the system is a push system. In a pull system, the order is initiated by a unit further downstream in the synchronized flow, thus no work center or station is allowed to start production for the sole purpose of utilizing equipment and employees (Vollmann et al., 2005). The concept of the pull and push system is illustrated in Figure 5.

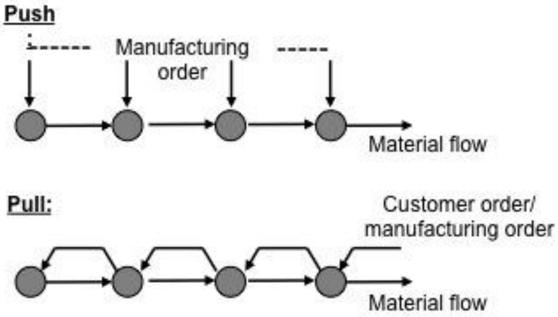


Figure 5: Illustration of push-based and pull-based planning (Jonsson & Mattsson, p.208, 2009).

Material consumption per produced item is put together on a *bill-of-material* (BOM) (Jonsson & Mattsson, 2009). For material planning methods, such as material requirements planning, the BOM is essential to keep track of how material is consumed.

2.5. Material handling

The logistics function coordinates resources such as handling equipment, load units and facilities through different organization strategies. A common trade-off is the trade-off between costs of storing versa cost of handling (Lumsden, 1998). Facilities is the warehouse itself, handling equipment is forklifts, tow carts or automated conveyors and the like while organizational examples is using milk-run theory for frequent distribution rather than bulk delivery. The choice in either category is dependent on firm characteristics, thus is the material handling and whole internal logistics function case specific (Baudin, 2004). The following sections will briefly define some alternatives in internal logistics.

2.5.1. Forklifts and trains of tow carts

Traditionally, the forklift has been the main manual handling and transportation vehicle for internal logistics (Cottyn, Govaert, & Van Landegham, 2008). A forklift mainly exceeds in its flexibility in undertaking all tasks required in internal logistics throughout the flow(Cottyn, Govaert, & Van Landegham, 2008). One main issue with forklifts is the problem to monitor and calculate cycle times. Assuming more than one forklift are used within the same task pool, problems with availability versus idle time occur and add inefficiencies worth considering (Baudin, 2004). So, in practice over dimensioned systems are common (Cottyn, Govaert, & Van Landegham, 2008). Other drawbacks are waiting times and safety. Forklifts are hazardous; they pose a threat to personnel and can cause serious material and infrastructure damage, thus safety issues are one of the main drivers towards the forklift free plant. (Cottyn, Govaert, & Van Landegham, 2008). Forklifts are most effective when pallet sized transports are demanded and the consumption matches a pallet sized batch (Baudin, 2004).

So, what is the best option when the opposite (many different items, small batches and high frequency) are demanded instead? According to Baudin (2004), a train of tow-carts is the most suitable when a mix of items need to be delivered with high frequency. Items are delivered in boxes, containing a smaller amount, on a tow-cart train with very frequent deliveries as opposed to the forklift. Typically tugger train operates a fixed route with a specific frequency in order to secure supply (Baudin, 2004).

2.5.2. Load units

A load unit denotes the packaging in which one or a set of items are delivered in. Examples are; a pallet which typically holds heavier, bulkier or larger amounts of items; a plastic container, much smaller in dimension containing less items and or smaller items. Standardized load units facilitate more efficient transportation; however return flows have to be created.

2.5.3. In-plant milk runs

To economically delivery smaller consignments with a high frequency, materials cannot be delivered in pallets with forklifts since forklifts are a poor fit in a repeatable flow(Baudin, 2004). Consequently, a system with less flexibility and greater reliability and predictability is suitable. If a fixed route is identified, in which the material is to be fed each loop; a system similar to a bus route with systematic departures/deliveries could be set up (Baudin, 2004). These are called in-plant milk runs. Baudin (2004) lists four characteristics: recurrence period is tens of minutes, not hours; delivery quantities are single pieces to bins, not pallets; they are managed under one organizational unit; and finally they are performed in a controlled environment. In conclusion, in-plant milk runs enable fewer goods in inventory through smaller batches and higher reliability while at the same time deliver frequently to a low cost.

3. METHODOLOGY

In order to fulfill the purpose with this master's thesis, a mix of established research methods is used. The methodology chapter will present and discuss methods relevant to support research within the case study object's environment. Firstly overall research design is discussed in order to set the thesis in its proper environment. It is inarguably found that the thesis fits the prerequisites of a case study, which is why the concept of case study is further elaborated. Secondly, having put the thesis in its proper research environment, information collection and processing of collected information are discussed. Primary versus secondary data and how they relate to this particular topic is also covered. Afterwards the information, data and theory connected to the excel model is described. Finally, the validity and reliability of chosen methods are discussed and complemented with some reflections regarding criticism to the sources used in the thesis.

3.1. Research methods

Research is required to be performed differently in order to best fit specific characteristics for each research object. To secure that adequate results are reached, the purpose can be used as guidance to what overall method to use (Karlsson, 2008). Furthermore, the purpose also point to whether quantitative or qualitative variables, or a combination, are best suited to describe the chosen phenomenon. In this master thesis, to answer how fluctuations affect internal logistics, a combination is the most suitable. The thesis is performed at Autoliv's facilities in Vårgårda, Sweden. According to Yin (2009), a case study is suitable when studying; (1) a contemporary set of events at a specific location, and (2); with the objective to answer a *how* question. The case study, as an overall method, is also suitable for combinations of qualitative and quantitative methods (Yin, 2009). Case study is therefore the overall method used in this thesis.

3.1.1. Case study

A case study is an empirical research method that investigates a contemporary phenomenon in depth within its real-life context; especially where the boundaries between the phenomenon and context are not clear (Yin, 2009). The case study is thus the opposite of an experiment, where the phenomenon is taken out of its real-life context and put in a controlled environment. Research methods, as discussed in section 3.1, are split in qualitative and quantitative methods. A case study successfully considers both aspects when retaining the phenomenon in its context (Yin, 2009). This thesis is therefore categorized and performed as a case study. Typically, the case study has a clear advantage over other research methods when questions regarding *how or why* addresses contemporary events (Yin, 2009). In addition, choosing a method considering both quantitative and qualitative methods increases the reliability through the possibility to triangulate using several approaches and thus gaining a holistic view. However, the case study may not be applicable at a general level due to the particular nature of the case (Patel & Davidsson, 2003). Careful choice of case object will minimize this risk and increase the possibilities to generalize the results.

3.1.2. Quantitative methods

At its extreme, quantitative methods is used to test hypothesizes in controlled environments (Karlsson, 2008), but less strictly described they "*incorporate a process of observation; with data collection achieved through such processes as laboratory controlled experiments or structured surveys*" (Karlsson, 2008, p. 66); where the latter are performed in this thesis.

3.1.3. Qualitative methods

In contrast to quantitative methods, qualitative methods are "*at their extreme concerned with constructivism, interpretation and perception, rather than with identification of a rational, objective truth*" (Karlsson, 2008). Furthermore, qualitative process may either be analytical or interactional inductive, where in the latter, data collection and analysis are done in an alternating manner (Hartman, 2004). Common methods are interviews and surveys. In this thesis, interviews are to a great extent used to gain understanding for activities related to the internal logistics at the case company. Furthermore, a more interactive inductive approach is used.

3.2. Information collection

During the information collection process, two different types of information is gathered, theoretical information and data. Theoretical information is gathered through a literature review and data is collected from two different sources, primary and secondary. These information types are presented in the following section, starting with theoretical and moving onto primary and secondary data collection.

3.2.1. Literature search

To develop perceptive and relevant research questions and to support empirical findings, a review of literature within the area is performed. This search included; searches in scientific paper databases, Chalmers library resources, e-books, Google scholar, supervisor's tips and finally course content from prior courses.

3.2.2. Interviews

An interview can be categorized by level of structure, where unstructured resembles an ordinary conversation and structured closely follows a predetermined list of questions (Gillham, 2000). Somewhere in between is the semi-structured interview where the interviewee is allowed to elaborate and answer more freely. Furthermore, semi-structured, and also unstructured, interviews are commonly used in initial stages of information collection processes when the interviewer possess little to no knowledge compared to the interviewee.

During the initial stages of the thesis work several unstructured interviews are performed with respondents possessing detailed knowledge about production and internal logistics at the case company. Employees at the department of logistics and transportation at Chalmers University of Technology are also, during this stage, interviewed in order to broaden the knowledge in the specific matters stated in the purpose utilizing semi-structured interviews.

3.2.3. Direct observation

A very intuitive way to gain quick insight into how activities, processes and systems work is through direct observation. Direct observation allows the observer to see for him/herself and thus gain thorough understanding of the operations (Liker, 2004). The direct observation fit very fell with the interactive inductive approach used in the thesis work. During this thesis direct observation regarding production, logistics and planning is conducted in order for the thesis workers to quickly familiarize with the environment present at Autoliv.

3.2.4. Case specific data

Case specific information encompasses all data directly connected to the case study environment. It could for instance be documents, excel data sheets or information from the *Enterprise Resource Planning* (ERP) system. In this case study, data is collected from documents and excel-data sheets with information withdrawals from the business system at Autoliv (MOVEX), which corresponds to primary data sources. As well as information from prior surveys and manually created excel sheets, referred to as the article matrix and the product and trading matrix which are secondary data sources.

3.3. Data structuring and analysis

The information is collected from diverse sources, in different formats and together constitutes the environment in which the production and internal logistics function operate and interact. Simulation imitates reality and is, among many more reasons, appropriate when the internal interactions in a complex system are to be studied (Banks et al., 2005). Furthermore, simulation is commonly used within manufacturing and material planning. Based on common procedures, a model will therefore be created and used to simulate a set of scenarios each representing situations occurring at the case site and relevant to fulfill the purpose.

3.3.1. Excel model

Here the assumptions, theory and method resulting in the Excel model calculation structure are reviewed. The basic idea is to transform each product variants' BOM into internal logistics capacity bills for each product variant. Then for any combination of product variant and takt time, an average resource allocation per product variant can be deducted and summed together, thus forming the total average resource allocation on the internal logistics function for the demanded combination. Fluctuations in production, i.e. disruptions in the takt/output, due to situational combinations can then be quantified and analyzed.

Conceptually, the model is influenced by how MRP pulls materials through the inventory system but here how moving material requires internal logistics capacity. Capacity bills for each product variant, in terms of logistics capacity allocation, are therefore vital to analyze how logistics is affected when production output varies. In the model logistics work emerge through production takt times and no sequencing or work in progress is considered. Capacity bills are thus, due to described characteristics, a more viable option compared to other resource allocation methods (Vollmann et al., 2005). The capacity bill, in this format, holds the limited resource and is therefore interesting to measure.

The collected data within the case study are all used in different ways to construct the Excel model, for the model as such, the scenarios or as input into the model. BOM’s, product variants, assembly cell data and material flow routes constitutes the backbone in the model, while contracted production takt serve as input. Furthermore, observations made in production and interviews regarding problematic areas are the foundation for the scenarios.

3.3.2. Scenarios

3.4. In line with simulation techniques, a scenario will model variables will impose fluctuations for the internal logistics are for example the product variant mix, how larger more. All these scenarios, their prerequisites and in section 5.1 An Excel model how production affect the forklifts

In order to determine the current state at Autoliv and relate this to any fluctuating states, a model is required. The model is created through the method described in chapter 3.3.1 Excel model. In this study the model is limited to product variants in series production. The forklifts covered are the ones described in section 4.2.7, which also are the forklifts connected to logistic work tasks directly affected by the production cells. In short the model relates the takt time in production to workload per forklift in minutes per hour. The forklifts in question and their related material flows can through the model be compared. Different scenarios and how they affect the forklift operators can quickly be constructed and evaluated.

The model is coded in Excel and each product variant in series production is included through their bill-of-material, article characteristics, finished product properties and contracted production volumes. In order to translate pallet movements into time usage per hour, the time for a certain movement (or activity) are measured (see chapter 5.1.1). Through the logic in the model, a certain takt time drags components according to the bill-of-material, the article characteristics and product properties lead to pallet movements and through the breakdown of forklift related activities, and a forklift utilization rate per hour is calculated.

Several data sources are collected in order to retrieve the information needed for the model. Through a mix of data sources, both primary and secondary, large amounts of information regarding article characteristics, finished production properties, product variants, production contracts, BOM and additional information is retrieved. Primary data, taken directly from the business systems, are BOM, the standard times collected through a survey and aggregated demand data for all product variants in series production. Furthermore, direct observation and interviews filled the gaps not covered by the business system files. Secondary data, taken from the case company’s logistics department, are Excel files containing all articles and variants with properties covered and production contracts/takt times.

For any given combination of takt times for the production cells, the Excel model translates the production takt into forklift workload. Therefore, the model is used to quantify the transport demand for the entire logistics function and for each specific forklift. The model is later used to quantify the effect of how fluctuations in the production cells affected the perceived forklift workload. At the case company, contextual factors leads to fluctuation from and despite the leveled schedule. After covering these factors, scenarios relating these fluctuations to the normative state are presented.

3.4.1. Time study on the activity breakdown

In order to translate logistics work from the actual activity performed into the time it will allocate of the total time available per hour, the activities related to performing the logistics tasks are identified through interviews and direct observation. The activities are then, in detail, defined and a spreadsheet and a stopwatch is handed to the operators (spreadsheet included in Appendix VII). Thus, each activity is based on the operators own measurements. Conscious or unconscious bias to manipulate the times is reduced by informing and educating as to why these measurements are important to the operators and the system understanding as a whole. For each activity, all time measurements are aggregated and corresponding average values are calculated. The time measurements per activity is then used in the model to translate actual work to time usage per hour.

Activities resulting in fluctuations in production. The scenarios model how fluctuations from the leveled production schedule disperse the total production output among the production cells and therefore how the logistics work, as a consequence, also is scattered and/or varying. Through direct observation and unstructured interviews, situations yielding interesting and representative combinations are identified.

3.5. Validity

Validity in research refers to the findings is required to be *valid*, in order for the results to be reliable and trustworthy, and in case studies and thesis projects internal validity is ensured through method and data triangulation (multiple research methods and multiple data sources) (Karlsson, 2008). Furthermore, while internal validity aims at ensuring conclusions about factor relations are valid, external validity aims at ensuring possibilities for generalization of the findings to other environments. Through the various methods used within this case study internal validity can be increased. However, the possibility to generalize on the results is limited if no more similar case studies are completed. The discussion enables conclusions to be drawn in the environment of the case study, but the results are not necessarily applicable for similar systems or equipment in another environment.

4. CASE COMPANY – AUTOLIV SWEDEN AB

Chapter four introduces the reader to the case company and describes the case specific environment as well as defines the fluctuations scenarios, which is used. In this chapter, the case site and company, Autoliv in Vårgårda, is briefly presented in relation to its industry and product catalogue. Relevant parts of the Vårgårda facilities are later described as well as the operations conducted, to contextualize the problem approach. Products, production, planning, information flow, material flow, warehouse and organizational structure are covered completely.

4.1. Autoliv Inc.

Autoliv Inc., founded in 1997 as a merger between Autoliv AB, Sweden and Morton ASP, today develop and manufacture automotive safety products. At the time of merger, Autoliv AB, Sweden was the leading automotive safety company in Europe, while Morton ASP was the leader in North America and Asia (Autoliv, 2011a). In the 1950's, Autoliv was one of the pioneers within seatbelt technology and the name originates from this. Autoliv Inc.:

> *"Develop, market and manufacture airbags, seatbelts, safety electronics, steering wheels, anti-whiplash systems, seat components and integrated child seats as well as active safety systems such as night vision, vision and radar systems"*

Autoliv Inc. is present in 29 countries, with approximately 80 different plants and has 43000 employees, net sales is million $ 7 171 (*2010*) and largest markets are Europe (*38%*) and North America (*29%*). (Autoliv, 2011b)

4.2. Autoliv Sweden AB

At the facilities in Vårgårda, except for manufacturing, Autoliv Sweden AB develops and market automotive safety products and employs approximately 680 persons. In 2010, Autoliv Sweden was awarded "The Lean prize" by *Lean forum* with the motivation:

> *"Systematically and with laboriousness Autoliv Sweden have created a lean production system on high level. What distinguishes Autoliv is a structured and standardized work process from product development to production, with cross functionality as a natural element." (Industrinyheterna, 2010)*

At Autoliv standardized work is the backbone for process improvements, which are developed and realized through workshops throughout the company.

4.2.1. Products

A majority of the product types, offered by Autoliv Inc., are manufactured at the Vårgårda plant. Categories include airbags, seatbelts, steering wheels, anti-whiplash systems, seat components, integrated child seats and an active safety system. Each specific product is tailored into a unique variant, as required by customers' specific needs. A variant is therefore unique for a specific car model and thus kept alive until *end of production* (EOP) for that model. When a car model reaches EOP the related products are taken out of serial production and transferred into the spare parts flow. Though variants are almost identical in terms of BOM, differences are normally complexional or related to finished goods load unit size. However, steering wheels and seatbelt may differ more between variants than the other categories due to differences in the BOM. All products' BOM's, and respective variants', are within the range of 5-40 components and steering wheels and seatbelts account for the biggest differences between variants.

4.2.2. Production

All products are manufactured in production cells. Manufacturing is split in three production halls for serial production and one production hall handling spare parts, all adjacent to the warehouse. Each product category is dedicated to one or more production cells. Within each production cell, one or several customer's unique variants are manufactured. Furthermore, left or right, *Europa* (EU) or *United states* (US) market or yearly production volume per variant are also criteria's explaining the product/variant mix over the different production cells.

The actual output of a production cell is controlled by a takt and changes in takt are achieved through changing the number of operators active in the cell within certain limits. So, each can have several output levels depending on the staffing and these are called *production gears*. These production gears are referred to as gears later in this thesis. These gears are not always linear, i.e. two operators do not necessarily double the output against one.

At Autoliv, there is a system for managing the actual production queue in production called *rail management*. Rail management is illustrated in Figure 6, and enables the production cell queue planned production orders, in comparison to a fixed system when all production cells is forced to more or less match the planned orders in scheduled time. Rail management means that the production cells are allowed to deviate from the planned schedule, within limits. The planned orders are put into queue on the rail and removed from the rail when they are produced.

The rail consists of three different areas, green, yellow and red, which represent the variation from the schedule. The green area means that the production is synchronized at a satisfactory level. The yellow area shows that the production is too far behind and the production manager are prompted to increase production pace in order to get the production back on schedule. If production orders are stacked all the way to the red area, the plant managing group is alerted and a workshop to solve the issue is initiated. Production is organizationally divided between three different groups, which handle the production of products with similar characteristics. These three groups are sido/front, IC and special/buckle.

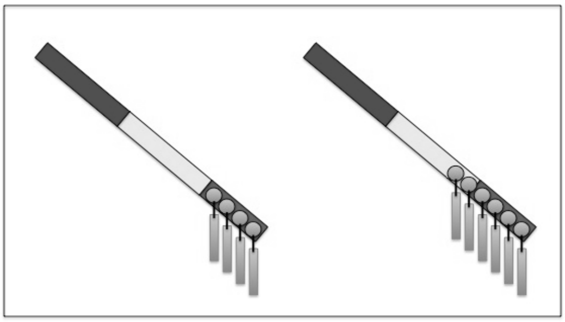


Figure 6: Principal illustration of the rail management system used at Autoliv. The left rail displays a production cell within the limit and the right rail illustrates a production cell exceeding the allowed queue limit.

The flow through each production cell is mechanized to different extent. In some production cells almost all tasks are mechanized and operators only serve components, while in other production cells almost exclusively involve manual assembly. The generic, representative, cell however includes a mix, where manual assembly and mechanization complement each other. The material facade is close to where assembly is and thus pallets with are sought to be avoided, but yet they exist in some cells. Material is fed and finished goods are fetched at the production cells either through manually handled boxes by tow cart trains or by in pallets by forklifts.

4.2.3. Production planning

Autoliv's customers each purchase a collection of variants (see section 4.2.1) and actual consumption takt is regulated by two-week contracts in detail describing which variant and amount demanded. These contracts are the input to the production planning process. The total volume demanded per variant is then split over the available up time for its particular production cell. The pace set over the leveled schedule is compared to the maximum takt time for the production cell and if the proposed takt time exceeds the maximum possible the planned takt is altered. To meet the excess demand production is conducted on the second work shift or during weekends. For some production cells there are several product variants within the same contract and production is alternated between these variants. However, full mix is never utilized due to mismatch in finished goods unit sizes and unfeasible change-over times. Several containers for finished goods cannot be fitted in connection to the production cell, only enabling production of one variant at the time. Suitable batches, in regards to change-over times and finished goods unit size are therefore produced in a leveled mix during the contract period.

4.2.4. Information flow

Production is initiated through production cards containing 30 minutes production. The production cards are is placed in the desired mix in 30 minute slots at a so called *Heijunka board*. The production cards are placed on a rail at the production cell and as long as the production card is consumed at the proper rate, the rail signals green. Yellow and red denote when production drag behind the leveled schedule.

Production kanban cards are used to replenish articles at the production cells from the flow racks in the warehouse. At the warehouse, similar kanban cards are used to replenish the majority of the flow racks from the pallet racking.

In addition, some inbound empty finished goods containers, articles, scrap, empty pallets and similar miscellaneous flows are not included within the kanban flows and are initiated through go-see or other communication. They can, however, still be related to series production by calculations and are thus mapped as stencil values per unit produced. They are in general bulkier.

4.2.5. Material flow

The production cells require components and each type of component is contained in a standardized load unit. Load units are as big as full pallet with rims, to medium- and small sized boxes possible to lift manually. In consequence, each produced unit will eventually have consumed a full box of components and this empty box needs to be retrieved to the warehouse. Similar reasoning applies for the finished goods which require packaging to be transported to the production cell and finished goods in packaging to be transported out. This results in four primary flows; inbound components, inbound finished goods packaging, outbound empty boxes and outbound finished goods.

The primary flows are either performed with forklifts or tow cart trains. Either flow can be served with forklift or tow cart trains, thus no general rules apply to which flows are performed with either set up.

Components going in to the production cells are transported in three different ways; directly from the goods reception to the production cells, in which the transport is performed by a forklift; from the warehouse either by forklift, when required, or by tow cart trains to the production cells. However, the forklifts are affected also by the tow cart trains flow since forklifts re-fill the flow racks.

The packaging containing components create a return flow of full pallets with rims, medium- or small sized boxes. For components transported to the cells in plastic boxes, plastic wrapping or cardboard boxes, the return flow is handled by the tow cart trains. However, the empty load units are collected at certain areas within the warehouse for further transportation by forklift to recycling, either scrap or return loop to supplier. For the larger load unit, pallets with rims or equivalents, the return flow is handled by a forklift all the way from the cell.

Forklifts transport inbound finished goods packaging to the production cells if the product is packed at the cell. For some cells, however, products are packed in the warehouse in which case the forklifts bring the finished goods packaging to the corresponding packaging area.

If the finished goods are packed at the production cells, a forklift transports the finished goods to the warehouse. Alternatively, the products are packed in the warehouse, in which case a tow cart train brings the goods to the warehouse and a forklift move the full container to the finished goods area. In addition, some finished goods require more packaging and is therefore taken to another area by forklift prior going to the finished goods area.

In short, the above describe the primary material flows in general. All the flows differ dependent on what product variant that is currently produced in the cell. To what extent the product variants differ, is different from cell to cell. In some cases it is only design, such as color on the covers, while in some cases it is either a single belt buckle or a double belt buckle which may require different finished goods packaging.

4.2.6. Warehouse

The warehouse is placed adjacent to the production halls and is separated in sections depending on the goods stored in each section. Denotations, relative locations and position in relation to the production halls are shown in Figure 7. USM1, SM1P SM23 and SM4 are warehouse cells and hold all inbound components in pallet racking with regular pallet shelves or flow racks. In addition, finished goods not packed at the cell are packed here. Furthermore, these sections are dedicated to the closest production hall. Later in this thesis these areas are referred to as cells. FGS is the finished goods area where the pallets are stored in a pallet racking. Finally, inbound and outbound goods squares are located close to the docks and supportive functions such as packaging, preparation and a cold warehouse are shown in relation to the primary sections.

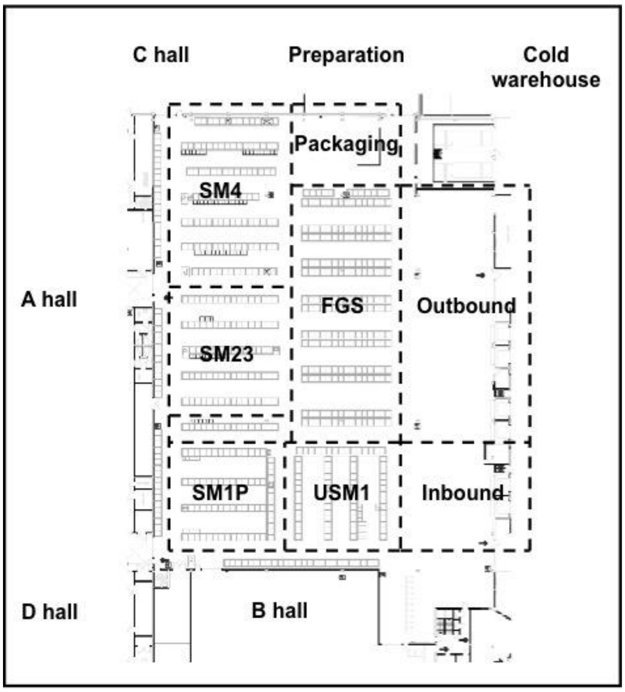


Figure 7: Warehouse layout at Autoliv Vårgårda, including the different cells within the warehouse and relative location of production halls and other key areas.

4.2.7. Organizational structure

The material flows are performed under the *autonomous manufacturing group* (AMG) material flow group, which are organized within two *autonomous manufacturing team* (AMT) organizational units; *receiving center* (RC) and shipping. AMT RC handles goods from the inbound goods reception until the small box display at the warehouse cells' flow racks and AMT Shipping handles the flow of finished goods from the production cells to outbound, and their fields of responsibility breakdown is shown in Figure 8.

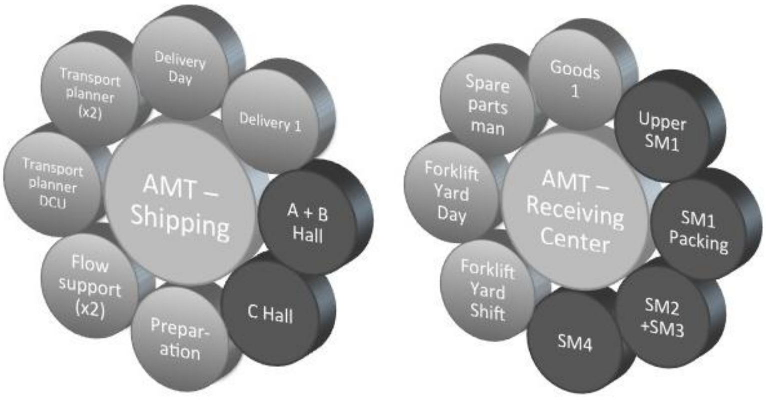


Figure 8: AMT receiving center and AMT shipping fields of responsibilities' each manned by one operator. Darker dots represent forklifts within the scope of the case study.

AMT – RC: The receiving centers fields of responsibilities consist of tasks performed with forklifts inside the warehouse and outside on the yard. However, only the darker dots are within the scope in the case study. The four forklifts' represented by the dark dots main tasks are assigned to a certain area within the warehouse called a cell; these cells are illustrated in Figure 7. The cell forklifts differ in that they are directly affected by the takt in the production cells. In general all these cell forklifts perform similar tasks; re-fill empty flow rack and floor picking positions, seal finished goods containers and move to finished goods area, support inbound goods in re-filling pallet racking, re-fill empty finished goods containers and bring finished goods eligible for wrapping to the wrapping area. The difference is to what extent these tasks are performed in each cell. One cell does not handle any sealing of full finished goods containers at all while one cell have seven packaging positions.

AMT – Shipping: The shipping unit's field of responsibilities consists of tasks performed with forklifts inside the warehouse, as well as planning of outbound deliveries. The darker dots are directly affected by the takt times in the production cells, which is why only these are within the scope of the case study. In general, the A+B Hall and C Hall forklifts handles the material flows in and out of the production cells not covered by the tow cart trains; later in this study these forklifts are denoted Abhall and Chall. This concerns handling bulkier (heavy and/or high volume) inbound components on pallets, but mostly inbounds packaging for finished goods and full finished goods units. In addition, these forklifts control the finished goods around the wrapper and further to the finished goods area.

5. ANALYSIS

In the analysis, results from the excel model are presented in order to create a starting point for the discussion. In this chapter the excel model used to calculate the amount of work for the forklift operators is presented. Secondly the activities performed at Autoliv leading to the different scenarios, as well as the scenarios is described and motivated. Then the results from the different scenarios is presented and analyzed. The analysis begins from a case specific perspective, for each scenario, and moving further into analyzing the results from a general theoretical perspective. The analysis chapter ends with a summary and reflection upon the normative state in comparison to the five scenarios. The full results are included within Appendix I to Appendix VI.

5.1. An Excel model how production affect the forklifts

In order to determine the current state at Autoliv and relate this to any fluctuating states, a model is required. The model is created through the method described in chapter 3.3.1 Excel model. In this study the model is limited to product variants in series production. The forklifts covered are the ones described in section 4.2.7, which also are the forklifts connected to logistic work tasks directly affected by the production cells. In short the model relates the takt time in production to workload per forklift in minutes per hour. The forklifts in question and their related material flows can through the model be compared. Different scenarios and how they affect the forklift operators can quickly be constructed and evaluated.

The model is coded in Excel and each product variant in series production is included through their bill-of-material, article characteristics, finished product properties and contracted production volumes. In order to translate pallet movements into time usage per hour, the time for a certain movement (or activity) are measured (see chapter 5.1.1). Through the logic in the model, a certain takt time drags components according to the bill-of-material, the article characteristics and product properties lead to pallet movements and through the breakdown of forklift related activities, and a forklift utilization rate per hour is calculated.

Several data sources are collected in order to retrieve the information needed for the model. Through a mix of data sources, both primary and secondary, large amounts of information regarding article characteristics, finished production properties, product variants, production contracts, BOM and additional information is retrieved. Primary data, taken directly from the business systems, are BOM, the standard times collected through a survey and aggregated demand data for all product variants in series production. Furthermore, direct observation and interviews filled the gaps not covered by the business system files. Secondary data, taken from the case company’s logistics department, are Excel files containing all articles and variants with properties covered and production contracts/takt times.

For any given combination of takt times for the production cells, the Excel model translates the production takt into forklift workload. Therefore, the model is used to quantify the transport demand for the entire logistics function and for each specific forklift. The model is later used to quantify the effect of how fluctuations in the production cells affected the perceived forklift workload. At the case company, contextual factors leads to fluctuation from and despite the leveled schedule. After covering these factors, scenarios relating these fluctuations to the normative state are presented.

5.1.1. Time study on the activity breakdown

In order to translate logistics work from the actual activity performed into the time it will allocate of the total time available per hour, the activities related to performing the logistics tasks are identified through interviews and direct observation. The activities are then, in detail, defined and a spreadsheet and a stopwatch is handed to the operators (spreadsheet included in Appendix VII). Thus, each activity is based on the operators own measurements. Conscious or unconscious bias to manipulate the times is reduced by informing and educating as to why these measurements are important to the operators and the system understanding as a whole. For each activity, all time measurements are aggregated and corresponding average values are calculated. The time measurements per activity is then used in the model to translate actual work to time usage per hour.

5.2. Activities resulting in fluctuations in production

In the case study several activities affecting the actual output per hour from the production cells and the workload for the logistics function are identified, through direct observations and unstructured interviews. Fluctuations are defined as; *variations in the output per production cell, due to activities different from activities present in a normative state*. Then what is the normative state? The normative state is an assumed production set up where leveling on production takt time is set on a two weeks basis according to the demand. The production is also leveled on product variant level with regards to overall total volume for 6 months ahead. In other words, disparities owing to fluctuations from work intense variants and not using fully leveled scheduling on variant level per production cell are avoided. The normative state could therefore be used when analyzing effects occurring when deviating from a leveled schedule. It is assumed that deviation from the normative state yield a change in workload for the logistics function, either increase or decrease.

In some occasions, certain product variants yield a significant change in workload for the logistics function, despite the production cell running at same gear, depending on which variant that is in production at the production cell. There is also, for many production cells, a mismatch between the overall takt set in the contracts and the actual takt possible at each cell; contracted takt time does not match gear output. Another issue is the system called rail management, further explained in chapter 4.2.2, where production is disconnected from the planned orders leading to fluctuations. Furthermore, there are some necessary processes in production where certain operations are dislocated from the takt time leading to batching, which inevitably leads to peak in output and thus demands significantly more work for the logistics function during short periods of time. There are also products and product variants with a very low demand leading to sporadic production, which in turn creates fluctuations. The different disturbances from a leveled production can be arranged in scenarios, Figure 9 is an illustration of the scenarios.

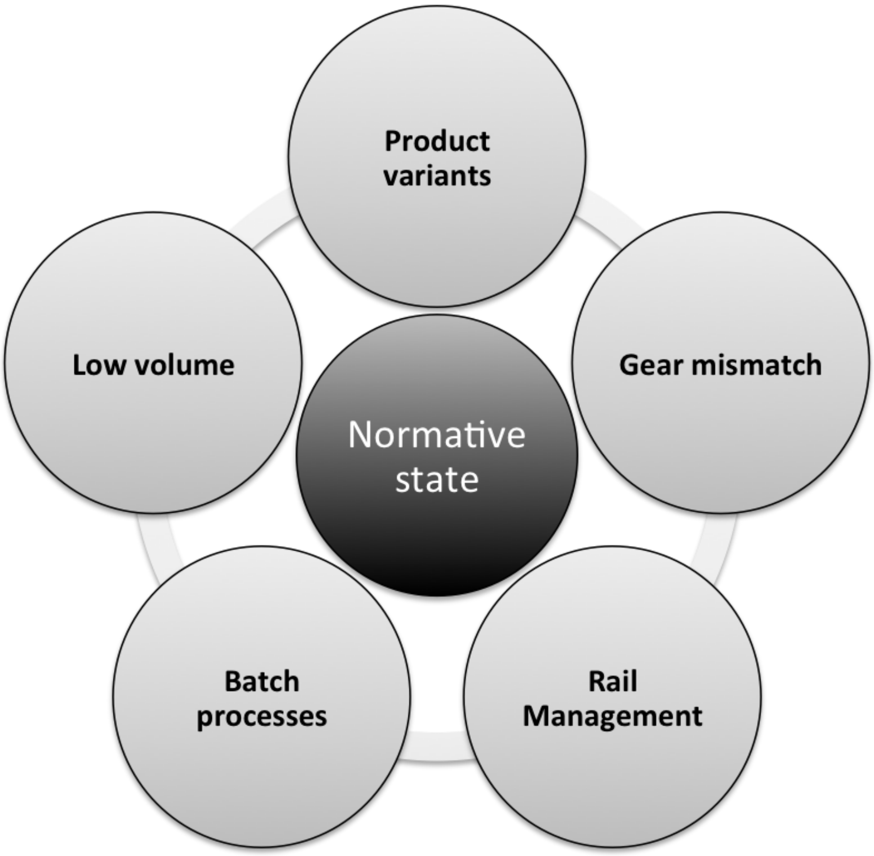


Figure 9: Illustration of the 6 created scenarios. The reference scenario is highlighted.

To be able to measure and determine the effects of these fluctuations mentioned above, a normative state is created. The normative state is truly leveled and provides a reference to use in comparison to the other scenarios. In this truly leveled production scenario the production is leveled in terms of both mix and volume. Takt-time is leveled during the entire contract time, which means that the production pace is constant during a two-week period.

The product mix is leveled according to the demand for a 6-month period. The product variants' demands are weighted against each other according to production cell and each demand contributes with its specific demand. This means that theoretically all products are produced simultaneously. If for example production Cell 1 produces two product variants A and B, and product A stands for 80 % of the demand while B stands for 20 %. Then 80 % of the production output is product A and 20 % is product B. If the production pace is 10 units per hour, 8 A's and 2 B's are produced every hour. In reality this set-up will not be sufficient due to a number of factors for instance set-up times for changing variant. If a cell produces 20 variants of a product then production set-up needs to be changed 20 times every hour. However, the scenario provides a good reference in terms of resource utilization, as the resource allocation is smoothed for the entire period, thus an indication of the average resource demand is achieved. In Table 2, the created scenarios are summarized.

Table 2: The scenarios tested in the model; a brief description per each and how they deviate from the normative state.

Number	Name of Scenario	Description	Difference from the normative state in the model
1	Normative state	The normative state which represents the average demand for transportation is truly leveled	-
2	Product variants	Production of only one product variant is taken into consideration	Instead of a weighted average of product variants being produced, only on product variant is produced
3	Gear mismatch	Production takt according to the available production gears	Instead of production takt according to the contract, takt time is restricted to the gear closest above/below the contracted takt
4	Rail Management	Productions is decoupled from the planned schedule on an operative level	The same as gear mismatch but the gear is not restricted to the closest gear above/below the contracted takt
5	Batch processes	Certain operations in production are decoupled from the takt and produced in batches	The work task coupled to the batched operation is performed in a batch
6	Low volumes	Production of low volume goods are impossible to level and thus produced irregularly	Production on new production cells are introduced at a feasible takt

5.2.1. Work intense product variants

According to section 4.2.2 Production, the rule of thumb is that similar product variants are assembled at the same production cell. However, being similar does not in all cases mean identical in terms of *BOM*, load unit for the component and/or load unit for the finished variant. For example, similar variants may include two or more components when being delivered to a certain customer and lack these components when delivered to the others buying the same product. This leads to an increase in the logistics workload, for that production cell, despite running at the same gear as with other less work intense variants. It is also common for some product families that the finished goods load unit differ from customer to customer. Thus, a load unit containing 10 units in comparison to 20 requires double the logistics work for that given gear. Furthermore, a certain customer may require a bigger front cover and thus the load unit may hold fewer parts per unit resulting in a small increase in logistics workload.

These differences, within the variants assigned to a production cell, lead to a higher work for the logistics function than the normative state. The opposite, smaller and fewer parts in bigger finished goods load unit per variant yield less work for the logistics function per produced unit. In conclusion, some variants yield a significant increase in production output and logistics work while others does not require at all the same amount of logistics resources.

In the product variants scenario, effects on the logistics function are tested by reallocating the production output to single product variants for each cell, in comparison to using an evened out mix explained briefly in 5.2.1. Which product variants that are selected for each cell is decided by the following criteria's: Highest total resource demand, lowest total resource demand, highest resource demand for specific forklift operator and lowest resource demand for specific forklift operator. In these calculations resource demand represents the need for transport and thus the workload for the logistics unit. Since there are six forklift operators subject to the study the scenario involves one study where an aggregated demand is at focus and six studies where the focus is demand for specific forklift operator.

5.2.2. Production gears and contracted takt time mismatch

In section 4.2.2 Production, it is explained how different gears in a production cell is equivalent to a fixed takt time and staffing. The overall takt time per two-week period is set according to contracts. However, in many cases the contracted takt time is not on par with the possible gears. To match the planned output, the production cells alternate between gears higher or lower than the initially planned takt. Thus, despite a leveled schedule, production cannot even out production pace and is instead forced to alternate. This is achieved through re-allocating the finite available staffing capacity among the production cells and inevitably resulting in some production cells gearing up and some down. Full gears at already work intense production cells in combination with lower gears at not so work intense will for example increase the overall output. The logistics work is not only redistributed within the production halls, it can thus also drastically increase or decrease overall.

This yield momentary difference in production output between the cells, where some cells, production plans are set towards contracted takt. However takt and gear are often not the same. A certain gear matches a certain takt and requires a fixed amount of staffing. A finite amount of staff can be move around a set of production cells and production output can thus vary around certain limits with a maximum and a minimum. However employees are restricted to movement between production cells connected to the same AMG.

In this scenario the number of operators is constant and determined by the total production demand. The number of operators is constant over each contract period, since fluctuations in employees on such a short time span is highly unlikely .The operators are redistributed among the production cells to create the highest or lowest impact on the total resource demand or resource demand for specific forklift operator. The distribution of operators is restricted to the production gears just over and below the production pace set by the contract. Production at Autoliv is conducted in teams; each team belongs to a group and redistribution of workforce is only possible within these groups, the different production groups are described in 4.2.2.

5.2.3. *Rail management*

The rails, as described in section 4.2.2, are used to control what and when production is supposed to start. The rail also indicates at which rate the production cell is producing in accordance to the leveled schedule. As operators are interchangeable between production cells, the rails are used to make sure all production cells are on par with schedule by moving around operators. So, despite the leveled schedule there is variation in the staffing, not only due to the gear mismatch described in section 5.2.2, at each production cell but also due to other factors.

This scenario is an extension of the gear and contract mismatch scenario. Instead of production cells being forced to operate between the two gears above and below the contracted takt time, the production is free to utilize any gear. The only restriction is that the entire workforce is fixed, set to the amount required to produce the demanded volumes and they are only able to move between production cells within the same production AMG.

5.2.4. *Batch processes*

The ordinary processes in the value chain may need to be complemented with an extra control station to secure quality, either for products subject to quality issues or new products required to undergo additional tests. Since the quality stations are moved around and not manned continuously, they act as a batch process from a logistics point of view. Often one operator is assigned this task when one, two or three full containers are ready for inspection. After the quality inspection is done all containers are taken to the finished goods storage. Thus, work is accumulated during a period of time and therefore a dip in logistics work prior to this can be seen while an increase is seen when the inspection is done. The effect of batch processing is tested by reallocating transport demand, supposed to be performed in accordance to the takt, to another moment in time. The operation affected in this case is the transportation of finished goods from buckles cells.

5.2.5. *Low volume cells*

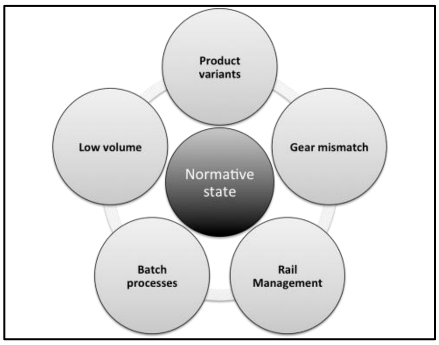
For some products that are produced in serial production the demanded volumes are low in comparison to the production pace. It is therefore hard to level these products over a long period of time without experiencing ineffective production. Therefore these products are excluded from the leveled contracts and are only produced in accordance to match customer orders. In some cases the production of these product variants are conducted on production cells, which are planned according to contracts and performed when excess capacity is available. Since production is taking place when the ordinary production is stopped the disturbance for the logistics function is negligible.

However in some cases the characteristics of the low volume product variants are very different from any other product with higher volumes making them impossible to produce on the same cell. In that case the low volume cells are given an own production cell, which is only operating when there is a demand for the product. Thus, production on an extra cell is initiated creating an increased demand for transportation.

This scenario is simulated by introducing production with a typical production pace on production cells that are not handled in the contracts. The production cells IC8 and

IC10 are chosen. Both those cells only affect two of the six forklift operators but they are chosen since they are not planned using production contracts.

5.3. Scenario 1: The normative state



In the normative state scenario a truly leveled production scenario is simulated. The production is assumed to elapse according to the leveled schedule and thus the resource demand, per definition, is leveled during the time period set. That makes scenario 1 useful as reference when comparing with other scenarios, each occurring at more or less special occasions. It also provides an indication of the average resource demand for the logistics function. However, being a modeled average state, it is not feasible to dimension the work force according to this measurement solely, mainly since it only includes series production and the forklift operators have other tasks in addition to the series flow.

The demand for transportation for each specific forklift operator in the truly leveled production schedule is illustrated in

Figure 10. As explained in section 5.1 the model recalculates pallet movements into work-time in minutes per hour. As seen in

Figure 10 the demand for transports between each specific forklift operator varies. It indicates that fluctuations in different work cells would disperse the workload differently. The forklift operator in production hall C has a workload of 56.5 minutes every hour, while the operator in work cell SM1P only has a workload of 31 minutes every hour. The C production hall forklift is utilized about 94 %, which is too high to manage at a long-term basis. The result can either be explained with the time weights per work activity is too big, or that this particular forklift operator is aided by other operators when required. At Autoliv, a forklift is regarded as fully utilized at 85% since the entire task pool also include tasks outside the series production and unscheduled breaks. This scenario also indicates that the forklift operators working in the production halls experience a higher workload than the forklift operators in the warehouse cells.

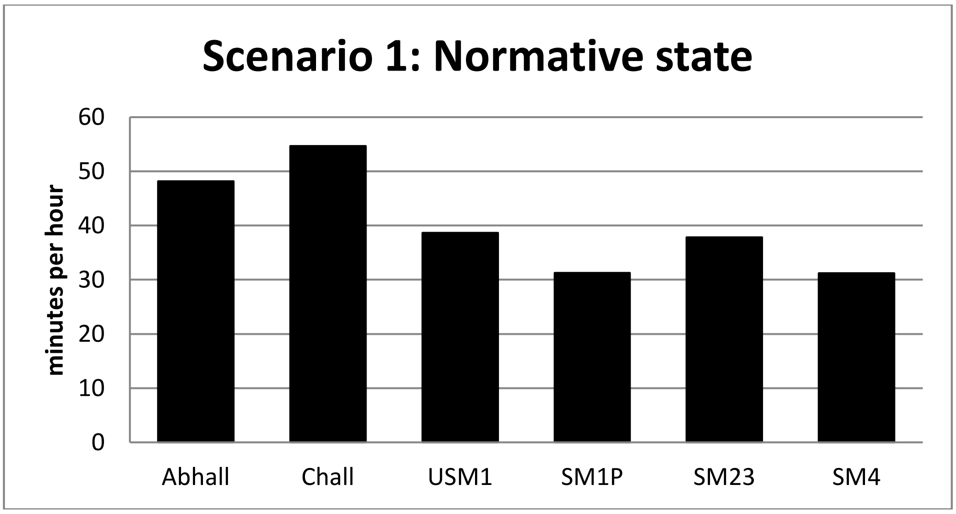
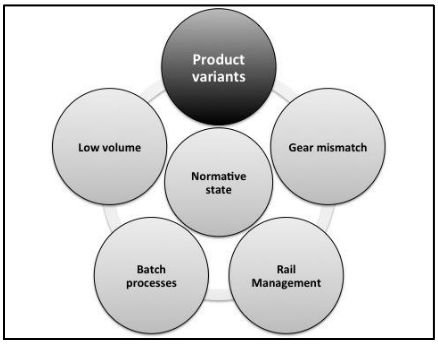


Figure 10: Workload in minutes, connected to series production, for the forklift operators at Autoliv in Vårgårda in the normative state scenario.

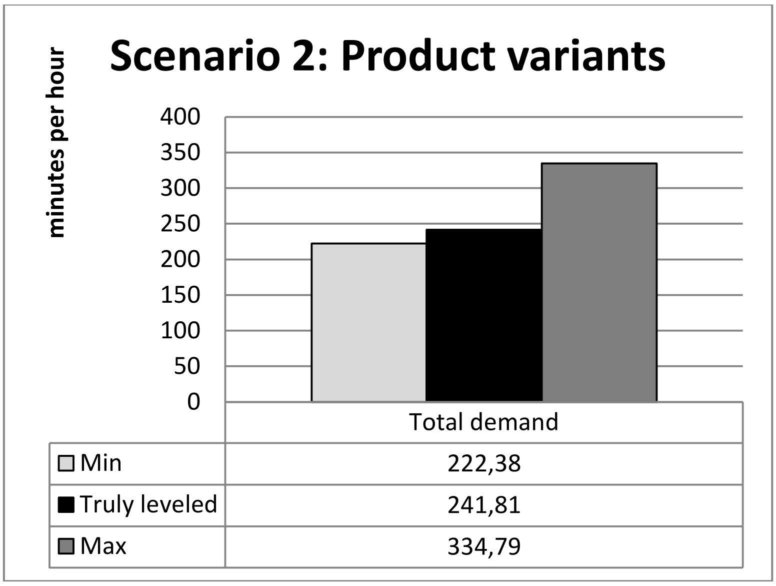
The normative state is not only useful as a reference to the other scenarios, it also represent the leveled schedule Autoliv is using, called the Heijunka board. Each production cell is individually planned on a per shift basis. At the Heijunka board full leveling, as assumed in the model, is not used since load unit sizes unable a fully leveled mix. However, it is still representative since the model evaluates full unit movements and the variation among the full unit loads and its dispersion is interesting.

5.4. Scenario 2: Product variants



The impact production have on transportation varies for different product variants as explained in chapter 5.2.1. If the product variants with the highest demand for transportation are produced simultaneously, the total demand increases. The opposite applies for the product variants that have the lowest impact. Figure 11, Figure 12 and Figure 13 displays the minimum and maximum demand for transportation in comparison to the normative state. For each production cell, any variant belonging to the cell is an option and thus many combinations are possible. Scenario 2 seeks to illustrate the variance in logistics workload between the worst and best imaginable scenario.

Figure 11 shows the aggregated demand for transport in minutes per hour. In this scenario, the product variants with the highest and lowest impact of the total demand for transportation are selected. The fair grey bar represents the minimum resource demand, the black bar is the normative state and the dark grey bar shows the impact if the worst possible product variants are manufactured in combination. The graphs in Figure 11 describe the actual demand for transportation for all forklift operators put together. Since Autoliv currently has six forklift operators, their maximum capacity is 360 minutes every hour. As seen in Figure 11 the maximum demand for transportation is not above 360 minutes per hour. Regarding from Autoliv’s 85% utilization limit, it is nearly 10% too much work per hour which imply that the worst case scenario is impossible for the logistics function to manage. The minimum demand for transportation is a lot closer to the normative state than the maximum demand, which imply that the less resource demanding variants are in demand right now. As the contract period chosen is representative for the forecasted mix among variants it is therefore less likely that the heavy maximum scenario happens. However, if the variant mix change drastically or over time the logistics function will suffer from increased problems to cope with production at times.

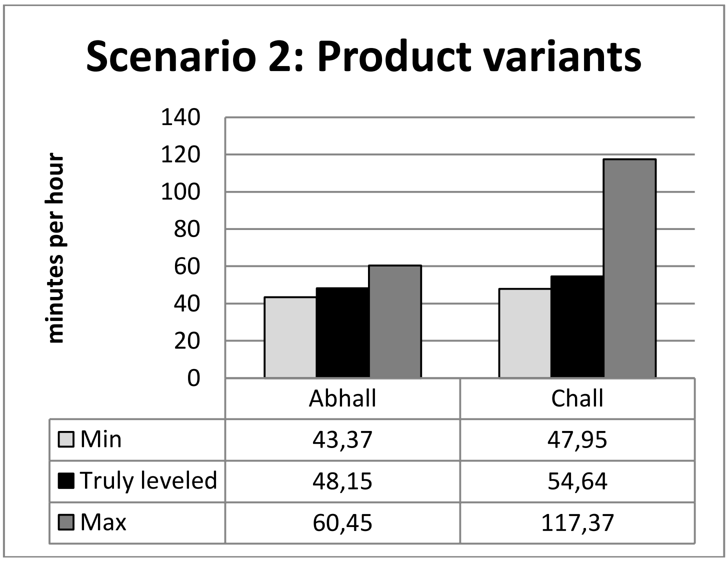


	Total demand
□ Min	222,38
■ Truly leveled	241,81
▨ Max	334,79

Figure 11: The total demand for transportation in minutes per 6 man hours for the product variant scenario.

Figure 12 illustrates the impact the worst and most suitable combination of product variants has on transportation for the forklift operators in the production halls. In both this case as well as for Figure 13, the product variant with the highest or lowest demand for transportation for each specific forklift are selected respectively. When analyzing the graphs, the same pattern as for the total demand is evident. The maximum resource demand is above both the absolute (100%) and actual capacity (85%) for each operator and the minimum demand is close the normative state. The fact that the normative state is closer to the minimum scenario imply, and further support, that product variants with lower demand on transportation are being produced to a greater extent than product variants with a high demand.

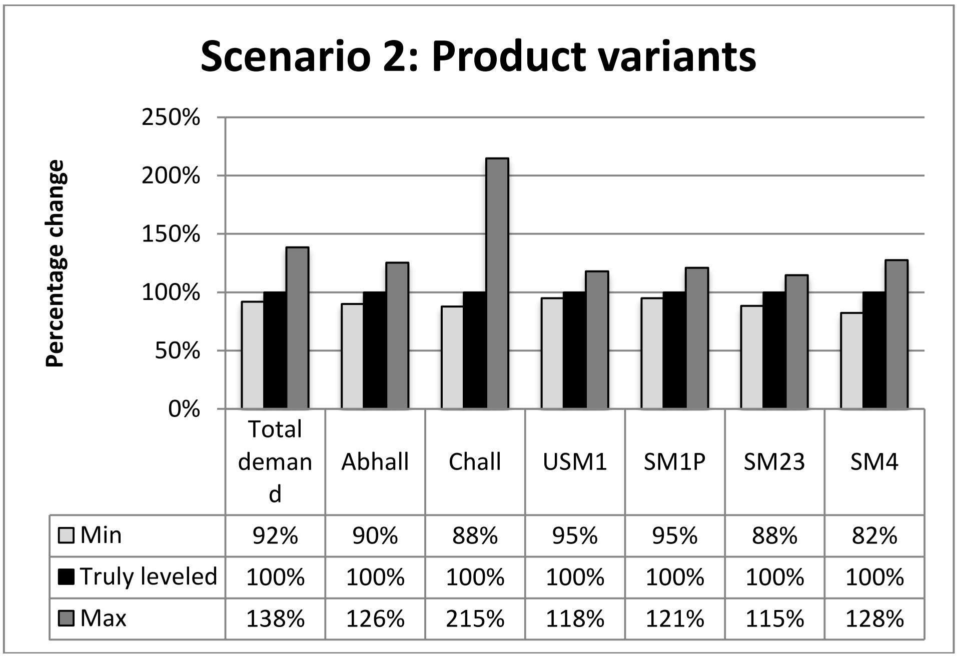
Worth noticing is that for the forklift operator working in production hall C, the maximum state allocate almost 120 minutes per hour, which means that it would take almost two forklifts to manage this.



	Abhall	Chall
□ Min	43,37	47,95
■ Truly leveled	48,15	54,64
▨ Max	60,45	117,37

Figure 12: Demand for transportation in minutes per hour, for production hall forklifts in relation to the normative state.

In Figure 13 the effect of a high or low resource-demanding product variant is displayed in terms of percentage change in comparison to the normative state. All forklift operators, defined in chapter 4.2.6, are illustrated in Figure 13 as well as the percentage change of the total demand. The effect for producing the worst possible product variant, from a logistics perspective, is not as clear for the cell forklifts as for the two production hall forklifts in terms of maximum demand. Less travel distance and more distinct activities make the warehouse cell forklift scale differently with product variant mix than the production hall forklifts. Finished goods load unit can dramatically change the workload and is affecting the production hall forklifts more than the cell forklifts.



	Total demand	Abhall	Chall	USM1	SM1P	SM23	SM4
□ Min	92%	90%	88%	95%	95%	88%	82%
■ Truly leveled	100%	100%	100%	100%	100%	100%	100%
▨ Max	138%	126%	215%	118%	121%	115%	128%

Figure 13: Warehouse and production hall forklifts' imposed resource demand due to variant mix in relation to the normative state.

In addition, the normative state 100% does not denote 60 minutes. 100% denote the normal resource utilization. A breakdown of the actual utilization in the worst scenario shows that none of the warehouse cell forklifts are above their capacity; not even over the 85% limit. Full figures are included in Appendix II. The maximum and minimum are both rather unlikely since there are around 50 production cells and over 200 product variants in serial production. However, the impact that each production variant and production cell has varies.

In Appendix II, the effect each specific production cell has on the logistics demand is illustrated. The graph essentially show that some production cells that are unaffected and some impose significant impact. The production cells with the most impact for each forklift are summarized in Table 3.

Table 3: Affected forklifts and total impact with top contributors to work allocation per production cell in minutes and percentage.

Operator affected	Production cell	Difference (min)	Difference (%)	Probability (%)
Total	DCU3	50	44%	1,4%
Abhall	PAB10	6,9	40%	9,8%
	DCU3	4,2	25%	1,4%
	DAB12	1,7	10%	20,1%
Chall	DCU3	50	72%	1,4%
	X14-2	9	13%	0,2%
USM1	DAB12	4,5	44%	20,1%
	DAB11	1,0	11%	2,7%
	PAB13	0,9	10%	25,4%
SM1P	SAB11	5,1	63%	2,6%
	SAB18	2,4	30%	50%
SM23	IC15	4,8	48%	10,0%
	IC9	1,8	18%	62,7%
	IC5	1,7	17%	45,5%
	IC13	1,2	12%	62,4%
SM4	SP2	3,1	22%	13,7%
	X14-2	3,0	21%	3,8%
	DCU3	2,1	15%	1,5%
	SP11	1,6	11%	25,9%

Table 3.

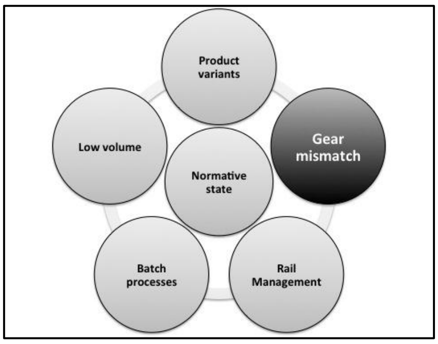
Table 3 summarizes the production cells which have the greatest effect on the separate forklift operators and in addition the total demand for transportation. *Difference in minutes* stand for the difference between the maximum and minimum demand for transportation for the all product variants produced on the specific production cell. Thus it denotes the variance a production cell could impose on the forklift operators. *Percentage of difference* stands for the particular production cells contribution to the total change of transportation demand between the maximum and minimum demand. Probability denotes to which extent the specific product variant is produced in comparison to other product variants on the same production cell. All production cells with greater impact than 10% of the total difference are included in the table. For most of the forklift operators there is two or three production cells that causes the changes in resource demand. It is also noteworthy that, in many cases, it is the same production cells that affect the forklifts.

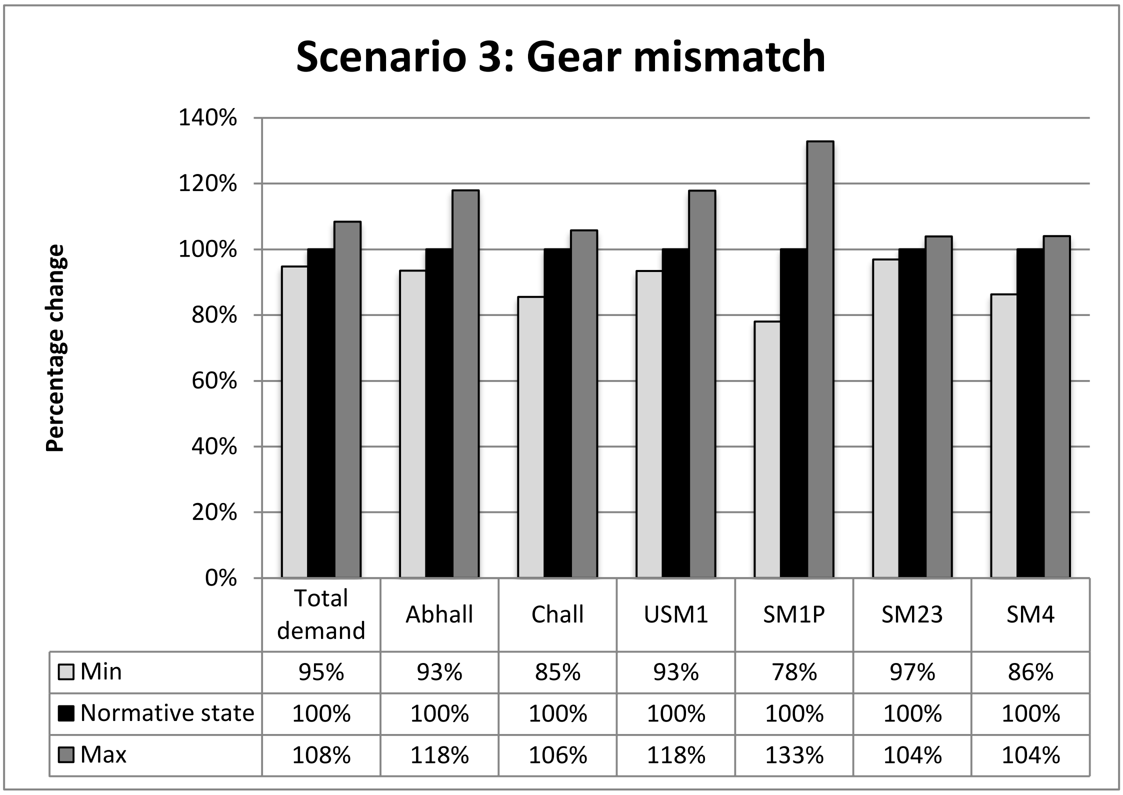
Additionally, the bar graph in Appendix II also shows that 19 of 51 production cells' impact on logistics are unaffected by which product variant that is produced. There are two reasons for this; the production cell only produces one product variant in serial production; the characteristics of the product variants are equal form a logistics perspective. Characteristics are such as; the same amount of articles in the BOM, similar packaging for articles and finished goods in terms of load carrier and components per load carrier. The unaffected cells increases the probability for the minimum and maximum states, but there are still too many product variants and production cells so the overall probability for either is relatively low.

The unequal logistic characteristics among the product variants manufactured in the same production cell are the reason behind the gap between the maximum and minimum demand for transportation. The uneven resource bills for different product variants in the same production cell are placing an uneven demand on an upstream process and the actual use of logistics resource is unbalanced. So, despite the leveled schedule, effects occur, normally associated with an unleveled schedule (Liker, 2004) occur, due to dissimilarities within the resource bills for product variants in the same production cell. Reducing the variance through making the resource bills more similar will reduce the *mura* waste for the internal logistics function.

5.5. Scenario 3: Gear mismatch

The production characteristics, not allowing takt times to perfectly match the contracted takt time and their impact on internal logistics is modeled in this scenario. Ignoring other factors, deviations from the leveled schedule, due to production variation, is bound to occur. In this scenario, fluctuations around the gears impose the variation in logistics workload shown in Figure 14.



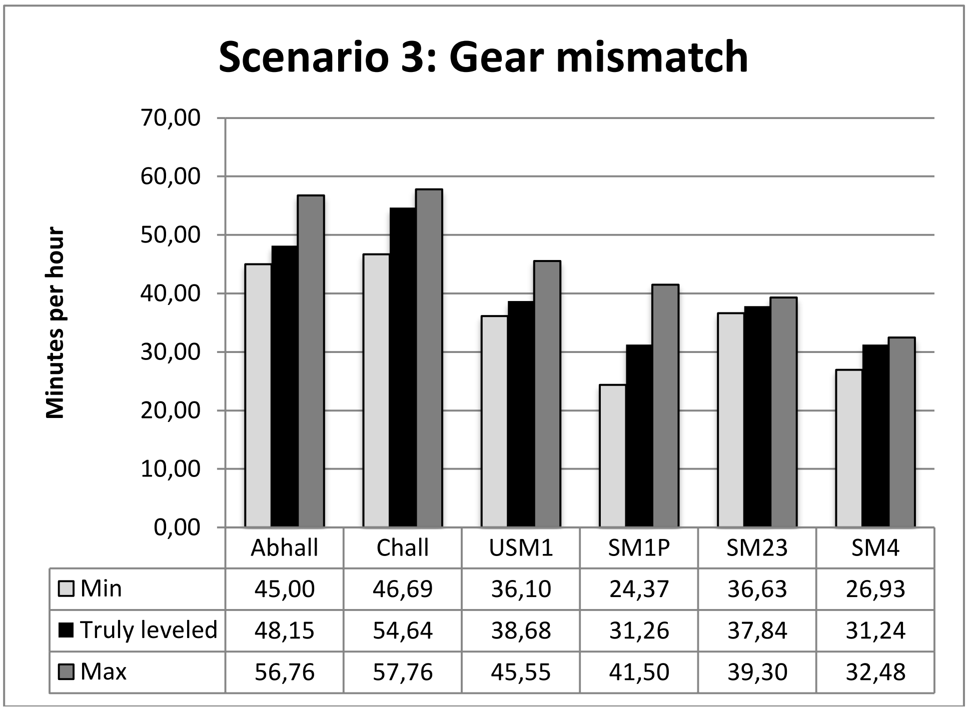


	Total demand	Abhall	Chall	USM1	SM1P	SM23	SM4
☐ Min	95%	93%	85%	93%	78%	97%	86%
■ Normative state	100%	100%	100%	100%	100%	100%	100%
▨ Max	108%	118%	106%	118%	133%	104%	104%

Figure 14: Total demand on transportation for the gear mismatch scenario in relation to the normative state.

The black bar graph denote the normative state and is also unbiased towards the effect tested. Maximum and minimum values are achieved through distributing a finite amount of operators to production gears either plus one or minus one, possible gear, in consideration to the contracts for each production cell. In the normative state, the contracted takts are either closer to the gear up or down, which is representative for how the reality works. For the contract period chosen, production cells relatively affecting logistics work the most are takted slightly beneath the contract while the production cells with relatively small logistics work are takted above. Therefore, the dark grey bar in the graph is, in relation to the fair grey, more far from the normative state for the total demand. The actual percentative changes are irrelevant as they will vary with the contract period chosen, what is interesting is the fact that there is a noticable change when operators are distrubuted differently. The relative amount of logistics work is different from production cell to production cell, when adding or subtracting one operator, and extreme combinations of either give the maximum or minimum state.

The effect on the specific forklift operator is in general more clear than for the total demand. It is therefore clear that the major change experienced is due to redistribtion among the work tasks rather an actual increase. The SM1P forklift experience the highest variations, both in terms of minimum and maximum impact. The effect is genereted due to the fact that SM1P serves production cells which are included in an AMG operating in to different production halls. Therefore, the production operators are free to move between production cells coupled with SM1P to production cells not served by SM1P. USM1 have a similar coupling, but does not experience the same magnitude in the fluctuations. The SM23 forklift operater is robust towards the gear mismatch, both in terms of minimum and maximum. The reason for this is that some production cells, served by SM23, require larger amount of operators, while at the same time, these production cells have low impact on transportation. Figure 15 displays the effect a minimum and maximum gear mismatch scenario will have on transportation. Since the normative workload is different for the operates a relative change in transport demand is of different significance. For instance a relative small increase for the production hall forklifts impose a greater problem in terms of capacity than for a work cell forklift.



	Abhall	Chall	USM1	SM1P	SM23	SM4
□ Min	45,00	46,69	36,10	24,37	36,63	26,93
■ Truly leveled	48,15	54,64	38,68	31,26	37,84	31,24
▨ Max	56,76	57,76	45,55	41,50	39,30	32,48

Figure 15: Demand for transportation in minutes per hour for each forklift operator in the gear mismatch scenario.

Other than showing the actual workload, these figures can be used to further argue that the magnitude of variation is indeed dependent on which production cells that is in focus. Each forklift serve a unique set of production cells and the magnitude of the variation in workload is thus different for each forklift.

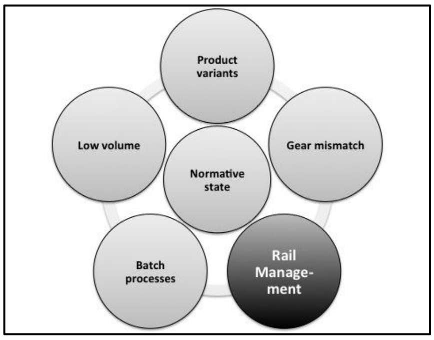
In Table 4 the production cells with the highest contribution to the workload for the total demand of transport and specific forklift operator is presented. *Difference in demand (min)* represents the impact adding one more operator to the production cell will have on transport demand. *Percentage of change* describes how much of the total workload the difference is. As the table shows, some forklift operators are very influenced by a few production cells while others are robust. This is mainly due to the difference in number of production cells served by each operator. It is evident that SM1P is extremly sensitive to changes in workforce in certain production cells, while SM4 is rather unaffected. The gear mismatches is thus leading to distortion in the logsitics workload.

Table 4: Production cells with the highest impact on the forklift operators when changing production gear.

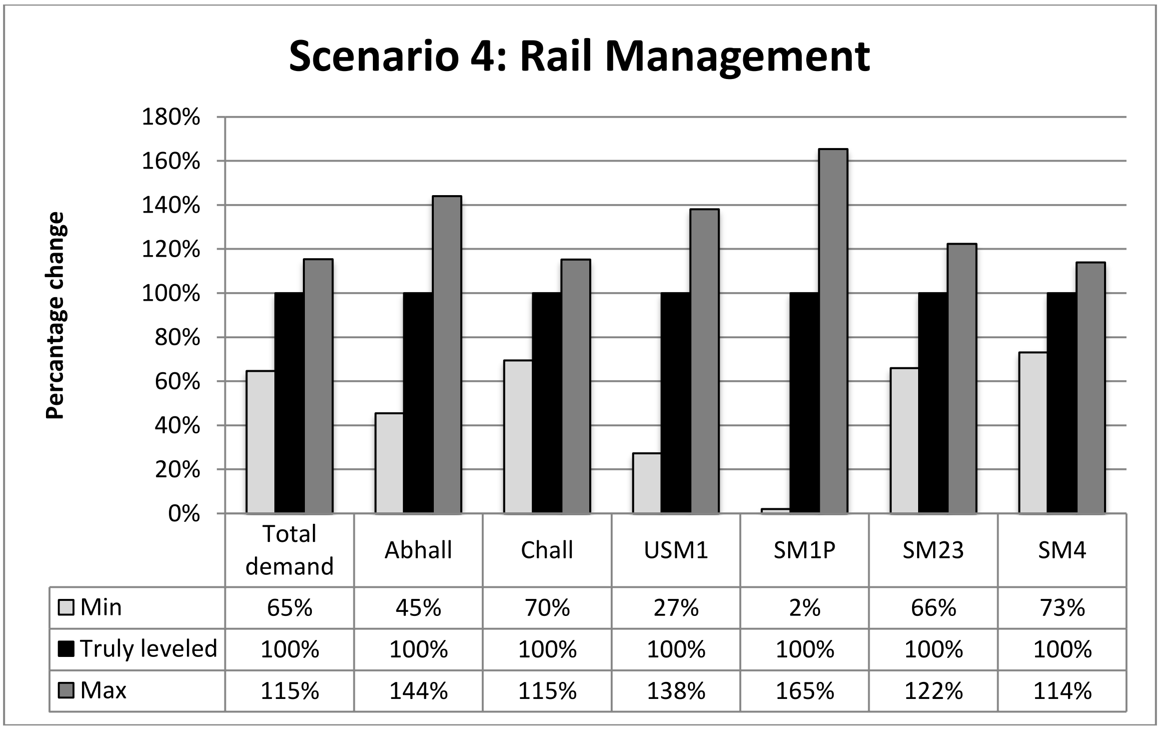
Operator affected	Production cell	Difference in demand (min)	Total demand (%)
Total	SAB11	7,5	3,1%
	PAB8	7,3	3,0%
	SP10	7,2	3,0%
Abhall	PAB9	3,0	6,3%
	PAB8	2,3	4,7%
	PAB10	2,0	4,2%
Chall	DCU3	3,9	7,1%
	SP2	3,9	7,0%
	SP5	1,7	3,0%
USM1	PAB8	5,0	13,0%
	PAB10	3,0	7,8%
	DAB12	2,6	6,7%
SM1P	SAB11	7,2	22,9%
	SAB19	6,8	21,7%
	SAB13	3,5	11,2%
SM23	IC15	2,2	5,9%
	IC16	2,1	5,6%
	IC6	1,6	4,2%
SM4	Omlänk	1,8	5,7%
	SP9	1,6	5,2%
	X14-5	1,2	3,9%

Mismatch with contracted takt will overproduce or create a bottleneck station; uneveness or *mura* is created. However, deadlines to adjacent customers are far longer than what the takt varies within due to the gear mismatch. In that sense, the production cell never become a bottleneck station per se, its rather alternating between small inventory build up or lack behind the schedule at times. The inventory alternations, around the contracted takt, will impose a small but percievable bull-whip effect on the most adjacent down- and upstream activities, which is the internal logistics function. The production output is discrete due to that production takt is determined by the number of operators per production cell. If the production cells had continuous output, the variance for the logistics function due to gear mismatch could be avoided since output could be kept at the contracted takt time.

5.6. Scenario 4: Rail management



Rail Management is similar to the gear mismatch scenario with the addition that the constraint only allowing gears just under or over the contracted takt time is removed. This allows modeling of how logistics workload will vary when rail management, explained in section 4.2.2, is used. The effect rail management in its most extremes will have on the forklifts is shown below in Figure 16. The black bar denotes the normative state for the total demand and for the forklifts 100% denote the actual work for each truck in the normative state. Again, dark grey and fair grey denote the maximum and minimum state respectively. Similar arguments as the ones made in section 5.5 apply to rail management too; the magnitude of the variation is not interesting. However, since all scenarios are based on *the same contract period*, they can be related to each other.



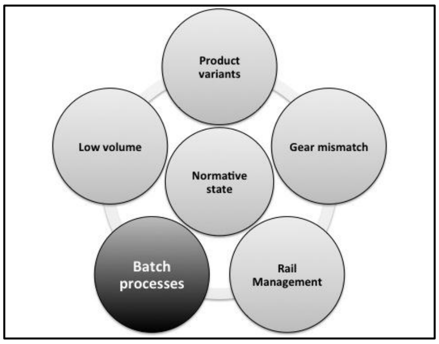
	Total demand	Abhall	Chall	USM1	SM1P	SM23	SM4
□ Min	65%	45%	70%	27%	2%	66%	73%
■ Truly leveled	100%	100%	100%	100%	100%	100%	100%
▨ Max	115%	144%	115%	138%	165%	122%	114%

Figure 16: Changes in transport demand in percentage for the rail management scenario in relation to the normative state.

For the overall workload, the maximum values are fairly close, meaning that the production cells during this contract period is takted close to gears with maximum logistics output. High maximum can be seen for the SM1P, USM1 and Abhall forklifts. However, all forklifts operators, but SM23 and SM4, are overburdened when the worst imaginable combination is in production when considering the 85% limit to utilization (This is presented in Appendix IV)

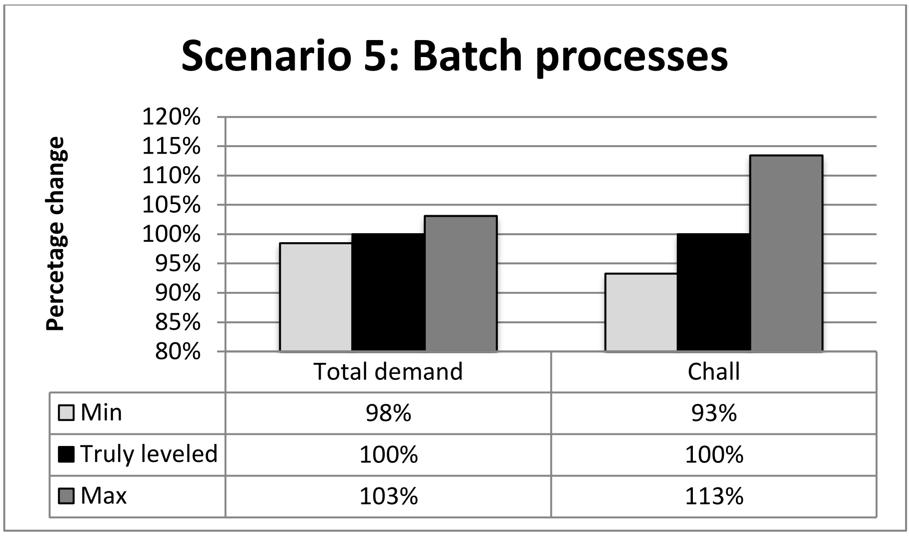
The significant difference, compared to the gear mismatch scenario, is the dramatic drop in minimum values overall and for individual forklifts. In the gear mismatch scenario, this is prevented through the constraint never allowing more than one gear lower than contracted takt. To realistically model rail management, production cells are allowed to be shut down, i.e. no gear or takt at all. The dramatic drop for the minimum values are therefore explained through that the most work intense, in logistics point of view, production cells are shut down in order to simulate when some production cells *gear up to catch up with lost production* while at the same time other cells are temporarily shut down due to the finite amount of operators. In particular SM1P and USM1 are affected the most by rail management on the minimum transport demand, which is due to the fact that they serve the same production AMG. This means that if production re-distributes their operators according to the rail management method, the minimum demand for transportation for these particular forklifts are decreased to almost zero, while the other cells experience a notable decrease. Rail management, even though the extremes are unlikely, imposes significant variation for the internal logistics function and disperse the, by the schedule, predicted logistics workload.

5.7. Scenario 5: Batch processes



At the case company, the batch processes scenario only occurs for a few products with the same characteristics in a cluster of similar production cells. Consequently, only some forklifts are affected. The cluster of production cells is the buckle cells, located in the C hall, and thus the C hall forklift is only studied. Upon release, each batch has an overall impact on total transportation, left-hand side of Figure 17, and on the C hall forklift, right-hand side of Figure 17.

The black bar denotes the normative state when quality control is assumed not to be batched and instead done continuously. The other two bars denote the variation occurring by batching the quality control process. The fair grey bar shows the relative workload overall when work is accumulating at the quality control station. The dark grey bar denotes the relative workload when the accumulated finished goods are done at quality control and released for transportation to the warehouse. The operation is accumulated over two periods and performed the third period.



	Total demand	Chall
☐ Min	98%	93%
■ Truly leveled	100%	100%
▨ Max	103%	113%

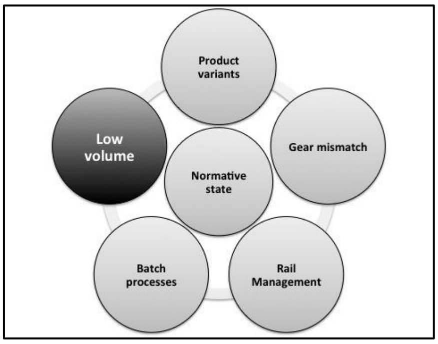
Figure 17: Change in transport demand for the batch processes scenario. Left bar graph: the effect on total demand; right bar graph: the effect on the Chall forklift.

The overall effect on total transportation is limited; however perceivable variation between the hour accumulating goods and the release hour is still noticeable. The significant variation is seen for the C hall forklift where the peak load is 14% higher than the normative state. Due to the already high workload for this particular forklift, the extra 14% puts it over 60 minutes of work per hour, not only the 85% but 100% (Appendix V). The variation seen is obviously dependent on how much that is being batched but already a few hours of production induce significant variation for the C hall forklift. In addition, the model takes partial pallet transportation into consideration, which is impossible or at least inefficient in reality which means that the variation, depending on finished goods unit load, may be even bigger. Unlike, the gears mismatch and rail management scenarios, the batch scenario only contribute with a higher workload and no dispersion among the forklifts.

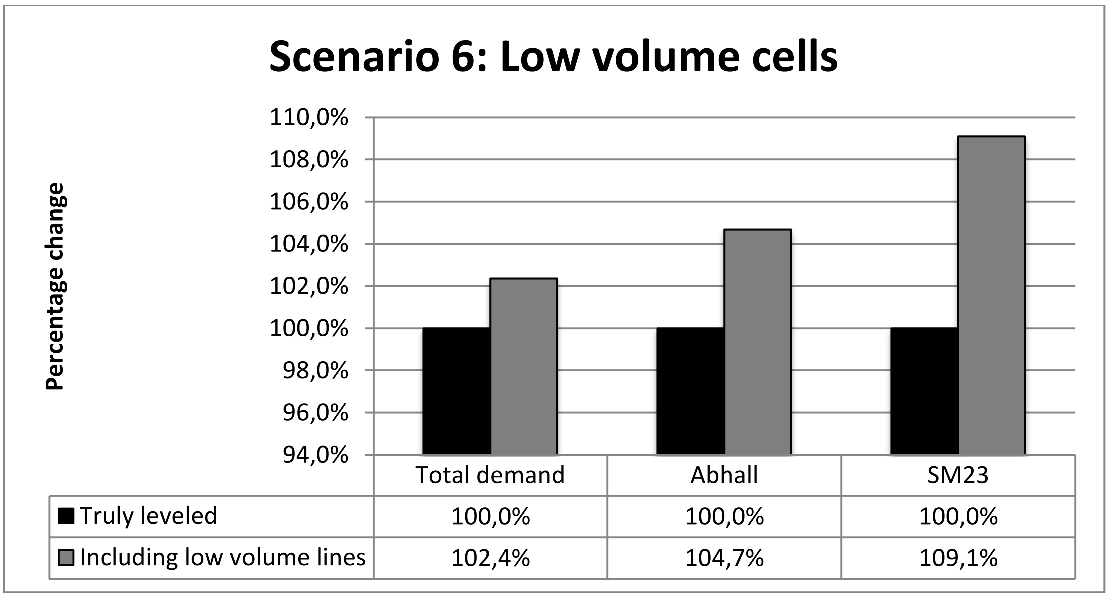
Lean principles are seeking to reduce batches (Liker, 2004). In addition, the quality can be feedback quicker and the process improved to secure future quality. However, in this scenario the batch process arises because quality control is batched. Developing a continuous process for the quality control would not only decrease logistics variation but also increase quality.

5.8. Scenario 6: Low volume cells

In this scenario production of low volume goods are introduced into the, by the model accounted for, series flow. Figure 18 displays the effect in percentage. In this case, production of the low volume cells IC8 and IC10 are included. In this case, some operators are moved from the serial flow lines to support the manually planned low volume lines. This means, other lines will consequently takt down and the effect on logistics could be diminished by moving between lines with similar logistics characteristics.



In Figure 18 the effect on the total demand, the forklift working in production hall A and B as well as the forklift in work cell SM23 is represented since those are the only ones affected by the production cells IC8 and IC10. Production at this pace on these specific cells is chosen as a plausible scenario due to information found in the manual dispatch lists. As illustrated below, introducing production of serial products with low volume, which is not produced on a daily basis, creates an extra demand for transport. The effect on the total transportation demand is rather low (2%) while the effect for specific forklifts could be significant. In this scenario the workload for the forklift operator in work cell SM23, is increased by just over 8 %.



	Total demand	Abhall	SM23
■ Truly leveled	100,0%	100,0%	100,0%
▨ Including low volume lines	102,4%	104,7%	109,1%

Figure 18: Changes in transport demand in percentage for the low volume cells scenario.

Even though the effect of utilizing production cells IC8 and IC10 only affects the production hall A and B forklift operator and the work cell SM23 forklift; there are other production cells which are not planned according to the leveled contracts, which affects other forklift operators. In Table 5 the impact of production cells, excluded from the leveled contracts is displayed. The figures are calculated using the maximum takt available for each specific cell. *Transport demand* represents the demand for transport the production cell has on the total or for each specific forklift operator. *The percentage change* indicates the increase initiating production for a specific cell will have for a particular forklift operator.

Table 5: Low volume production cells with the highest impact on the total transportation demand and for each specific forklift operator.

Operator affected	Production cell	Transport demand (min)	Percentage change (%)
Total	IC10	8,6	3,5%
	Slangpaket	8,3	3,4%
	PAB11	5,7	2,3%
Abhall	IC10	3,2	6,7%
	IC14	3,1	6,3%
	PAB11	2,4	4,9%
Chall	Slangpaket	6,3	11,1%
USM1	PAB11	3,3	8,8%
SM1P	SAB9	3,6	11,7%
	SAB12	0,6	2,0%
SM23	IC10	5,3	13,0%
	IC8	1,6	4,0%
	SAB9	1,5	3,6%
SM4	Slangpaket	0,9	3,0%

In the table, the same pattern occurs as for the scenario in the graph above; the effect on the total transport demand is limited while the effect for specific forklift operator is more significant. For instance, the effect IC10 has on SM23, SAB9 on SM1P and Slangpaket on Chall is significant.

5.9. Summary

The different configurations of the scenarios have various effects. In some cases, the variation is high overall or locally, while in other cases the variations are insignificant. However, what may be perceived as small changes in production will have significant impact on internal logistics. It is important to emphasize that all these scenarios can occur simultaneously except for Scenario 3: Gear mismatch and Scenario 4: Rail Management, whose effects are not possible to add together. Thus, the potential for variation in transport demand is greater than that of each specific scenario.

Scenario 4: Rail management is an extension of Scenario 3: Gear mismatch since production is altered according to the production gears. What differs is that Rail Management is allowed to use any gear possible, while production in the gear mismatch scenario is restricted to the closest gear above or below the contracted takt time. Therefore, the effect on the demand for transports is enhanced when rail management is applied in comparison to gear mismatch. Essentially the scenarios model the same effect.

Scenario 5: Batch process and Scenario 6: Low volume creates limited variation in total demand, but for the specific forklift operator the effect is significant. For instance, initiating production on IC10 will increase the workload for the SM23 forklift operator with 13%. Table 6 displays the minimum and maximum effect of each scenario for each specific forklift operator.

Table 6: A summary of the fluctuations caused by the scenarios tested.

	Product Variant		Gear mismatch		Rail Management		Batch process		Low volume
	Min	Max	Min	Max	Min	Max	Min	Max	Max
Total	92%	138%	95%	108%	65%	115%	98%	103%	102,4%
Abhall	90%	126%	93%	118%	45%	144%			104,7%
Chall	88%	215%	85%	106%	70%	115%	93%	113%	
USM1	95%	118%	93%	118%	27%	138%			
SM1P	95%	121%	78%	133%	2%	165%			
SM23	88%	115%	97%	104%	66%	122%			109,1%
SM4	82%	128%	86%	104%	73%	114%			

The product variant scenario causes the largest variations in transport demand, in the worst possible case; the total demand for transportation is above the total capacity for all forklift operators. It also causes the greatest peaks in demand for the production hall forklifts. According to Liker (2004), leveling the product mix is important because it evens out the resource demand. So without leveling of product mix the resource demand will vary, which is evident in Scenario 2: Product variants. The variation originates in unsimilar logistics characteristics or differing BOM's.

In theory, the Heijunka board, once set, should determine resource allocation for functions adjacent or supportive to production. The internal logistics function is one such function. However, the scenarios all describe several reasons why the leveled schedule is hard or impossible to strictly hold and how the deviation from the planned state will impose variation for the internal logistics function.

6. DISCUSSION

The discussion extends on the analysis and further outline the method chosen as well as discusses error sources. The purpose is to reflect upon the analysis and base the results and findings on a discussion relation to error sources and methodology choice. First a discussion on the chosen method is presented. Then a discussion on possible sources of error is provided. Finally the results are discussed.

6.1. Methodology

To fulfill the purpose of the thesis a broad approach is required. Information is; collected from a number of sources; presented differently; quantitative or qualitative; more or less static; in some cases incomplete and required to be complemented. Furthermore, the purpose to answer *how* fluctuations in production affect the internal logistics function fit well with the advantages of a case study. During the course of the thesis, the case study approach enabled adaptation to changing conditions, a high degree of freedom when and what information to collect and finally a general view enabling valid conclusions. *How* the fluctuations affect the internal logistics is case-specific. Full-scale examination of all situations is impossible within the time frame of the thesis, thus representative scenarios served to simulate occurrences, by the logistics function, perceived as problematic.

A substantial portion of the information collection involved withdrawing and flattening bills of material from the business system into Excel. Similar approaches are commonly used within industry to structure and analyze large amounts of information (Baudin, 2002). Therefore, it is intuitive to base the data structuring and analysis on Excel. In this particular case, including only series production, relating takt time, material requirements theory, unit load sizes and time measurement of standard forklift activities, Excel proved helpful and the results achieved would not be possible, within reasonable time, without Excel or similar software. The calculation structure, relating production takt into forklift utilization per hour, is required to handle the scenarios identified. To use the contracted takt times to develop a *fully* leveled normative state shown to be a solid base for comparison among the different scenarios.

The excel model calculate an average workload from a leveled schedule. In the larger scope, the whole planning horizon with actual average takt times, the model serves its purpose well. However, the fluctuations in production are happening over time and some changes take longer to come in effect than others. Different replenishment lead times, over time changing conditions and non-static workloads are examples and are dispersing the logistics work from the model. In manufacturing and material handling-system, more detail can be reached with software such as AutoMod (Banks et al., 2005). In combination with an advanced AutoMod simulation, AutoStat can be used for analysis of the scenarios run in AutoMod. In a project with more resources, as advanced simulation is both time consuming and knowledge intense, this would have increased the overall reliability of the analysis. Either choice of methods will, unavoidably, have error sources. Their impact and how they are reduced or eliminated to increase reliability in the chosen methodology are discussed within the next section.

6.2. Sources of error

Validity serves an important purpose for the findings to reach adequate reliability and for the possibility to draw reasonable conclusions. The analysis is highly dependent on the normative state to be representative enough to actually mirror how the fluctuations sought to model affects the internal logistics. Thus, it is a requirement to decrease error sources within the model to reach validity. Despite, through interviews and direct observation, ensuring material flows are correctly modeled and translated into forklift work, there are still error sources that could alter specific results. Three categories are identified: incorrect data, model specific errors and scenarios not being representative.

With the amount data acquired through Excel files there is a possibility that information regarding unit load size are incorrect, not updated or even varying within certain limits. For a particular flow this error will have an impact worth noticing, but the overall effect for the model is slim unless many articles consistently are incorrect. However, the Excel files are continuously updated so there is a minor chance this error will affect the overall results. Furthermore, the human factor when manually withdrawing bills of material for all product variants are more likely to have an overall effect. A numeral wrong will have a multiplicative effect on the particular flow and increase the workload by the same multiplier. In addition, the nature how the BOM are presented invites to include a page several times which will have a major impact. However, logic in the Excel programming prevents this from happening. The multiplier issue is still within the same impact level as the unit load sizes so the error source should be regarded as minor too.

The model, in the larger perspective, has some additional error sources worth discussing. To reasonably estimate consumption rates, only transportation work related to product variants in series production is included and thus each forklift will spend additional minutes per hour on forklift battery changes, individual breaks, communication, error reporting, quality follow-up/team meetings and miscellaneous tasks which is not included in the average hourly utilization.

Since the translation from pallet movements into actual time estimations is done through a set of activities, individually timed, an error source lay within inter- and intra-operator variance when performing activities and taking its time measurement. However, the time spent on time measurement is insufficient to fully secure that the activities is timed within statistical limits. The inadequate sample sizes will distort the relative importance per activity and thus affect how the effects from fluctuations occur. However, despite the limited sample size, the measured times can, and are used, in the model. In the analysis, focus is at the relative effect for a particular scenario versus the normative state. The time distortion, if there are any, will not affect this analysis since distortion is equal for both the scenario and normative state. The distortion will, however, have an effect on the model when used to estimate resource utilization. For analytical purposes the insufficient sample size represents a slim error source.

Disregarding data and model error, the constructed scenarios hold error sources if not tailored properly. The scenarios are made to represent the most extreme situations occurring through an effect. Unsuitable constraints and/or insufficient site understanding would have made the scenarios less efficient in demonstrating the effects on internal logistics. Through time spent on direct observation around the processes with complimentary interviews, the error source within the scenarios should be regarded as small.

Last, in a case study there is always relative limited possibility, depending on the case, to make generalizable conclusions for a generic case. However, for internal validity discussed error sources will have limited impact as discussed earlier. As for external validity, companies with similar or near to equal prerequisites may find these findings relevant but to strengthen or reject the findings more research is required.

6.3. Discussion of the results

In this section, the results are discussed from a general perspective and key results are brought to light. The discussion will first focus on nuances within the result and then the results and solutions are discussed using two different angles; first measures to diminish the effects of each scenario and secondly, measures to take when fluctuations occurs.

The results from the scenarios are unambiguous, deviations from a leveled production schedule affects the workload for the logistics function. However, the amplitude of the effect varies. Due to the characteristics of the model the effects are certain to arise for even the slightest changes. One can also argue that the natural fluctuations in comparison to the fluctuations caused by the different scenarios, determines the significance of the change. This is true to some extent; if the natural fluctuations are large in comparison to the effect from the scenarios, the effect can to some extent be disregarded. However the effect each scenario causes sets the average demand for transportation, from which the natural fluctuations varies.

Deviations from a leveled production schedule cause *mura* by distorting the logistics work load among the forklifts, but for some scenarios certain operators also experience *muri* when the workload gets overwhelming at times. Overburdening of the operators is apparent in many of the different scenarios, which makes it an important issue. The product variant and rail management scenarios especially highlight the existence of *muri*. Measures to hamper mura and muri within for the forklift operators are discussed below.

6.3.1. How to eliminate mura and muri for the forklift operators?

As mentioned above deviations from a leveled production schedule causes fluctuations for the logistics function, but the affect varies for different scenarios. For instance, different product variants cause the demand for transportation to alternate significantly, both for the entire logistics department and the specific operator. Even though probabilities for minimum and maximum scenarios are low the size of the impact imposes difference.

Utilizing two strategies can mitigate the fluctuations that occur; production of product variants can be mixed as much as possible or the differences in transport demand between the product variants can be reduced. Alternation between product variants is hindered by set-up times and the restriction to produce full unit loads. Therefore, it is important to continuously improve set-up times. It is also important to allow production quantities smaller than unit loads. This can be enabled by moving the actual packaging of finished goods to the warehouse by the tow cart trains or making space for packaging of more than one product variant at the production cells. The effect when switching between product variants has on logistics can also be mitigated by changing the logistics characteristics of the product variants in order to reduce differences. This is largely dependent on the BOM and capacity bill. The same amount of components should be included, use the same load carriers for components, with the same amount of articles and include the same amount of finished goods in packaging.

The impact of the gear mismatch scenario is not as apparent as the effect of the product variants scenario. However, the impact is not negligible and measures to minimize the fluctuations should be outlined. The reasons behind producing according to certain gears are connected to production efficiency therefore the gains in production efficiency should be weighed against the losses in inefficiencies in the logistics function. Switching between the gears more regularly can also reduce the impact on logistics. For instance redistribution of staff can be performed every hour or every half hour, thus providing a better match to the leveled schedule.

Rail Management is, as mentioned earlier, an extension of the Production Gear scenario. Thus, the same measures to mitigate the effect of gear mismatch could be used to decrease the fluctuations caused by Rail Management. Furthermore the degree of freedom of rail management could be decreased in order to reduce fluctuations. For instance the options of production gears can be reduced to the production gear just above and below the contracted takt time. The decision, on which premises Rail Management should function, should be based not only on production efficiency but also affects perceived by logistics.

Performing certain operations in batches creates fluctuations not only in transportation demand but also in production. One solution to this can be to include the process, which is batched in the one-piece flow set-up of the production cell. Theoretically this will allow for faster adaption and reduced risk to quality issues, since quality is the purpose of the batched process. However on practical level problems can occur, for instance issues regarding space at the effected production cell, or access to specific resources.

Production on low volume production cells creates fluctuations since there is a difference in resource demand. However to which extent this affects the logistics department depends on a number of different aspects. If production on the low volume production cells is performed while still producing according to the contracts the extra transport demand is added to the original demand. Otherwise the transport demands is changed dependent on from which production cells the operators are moved to the low volume production cell. Therefore the effect on transport can either be positive or negative. To mitigate the effect, low volume cells should be included in the takted contracts whenever possible. Another solution could be to determine rules for which operators that are moved in order to achieve lowest possible difference in transport for both the entire logistics department and specific forklift operator.

6.3.2. What measures to take when fluctuation occurs?

Even though measures to mitigate the effects of the different scenarios are possible, completely extinguish fluctuations is impossible. It is therefore important to handle these fluctuations with strategies. First of all, the effects need to be estimated and predicted in order to best decide which measures to take. Typically while one forklift operator experiences a peak in transportation demand other operator’s workload is decreased, as in the case of the gear mismatch, rail management and low volume lines. Thus one solution could be to redistribute the work tasks, either by creating a work pool for all forklift operators or by setting up measures to take at specific occasions.

A forklift task pool creates a lot of inefficiencies, transportation distances are increased and per definition a greater number of operators are needed in order to secure the same service level (Baudin, 2004). Redistribution of work task, while still remaining at individual tasks, enables efficiency levels to be kept and workload to be evened out. However not all work tasks are eligible for transfer. The efficiency loss caused by the extra travelling distance disqualifies some operations while some operations are connected which means that the same operator needs to perform the entire set. Redistribution of work tasks also increases the need for managing in terms of when and which tasks should be switched.

It should also be stated that most of the work tasks undertaken by the forklift operators is not compelled to be performed instantaneous as they arise which enables the operators to smoothen out the demand for transport individually.

7. CONCLUSIONS

Chapter seven summarizes the findings and determines whether the purpose of the thesis is met as well as determines its academic relevance. This chapter is separated into three sections; concluding remark, academic contribution and finally future research. Concluding remark reconnects to the purpose and briefly presents conclusions drawn from the findings. Academic contribution discusses the findings in relation to its academic relevance. Finally, the chapter is ended by a short recommendation for how future research may use the findings for future research.

7.1. Concluding remark

Reasonable conclusions are based on the findings in relation to the purpose and preceding problem analysis. The logistics function is closely tied to production and any fluctuation occurring, or deviation from the leveled production schedule, will have impact on the logistics workload. Product and component characteristics, organizational and structural decisions in production are three significant denominators if and how much changes from the planned state will affect the logistics function.

A part in the problem analysis focuses on the *lean perspective* not allowing other takt than the leveled schedule. The analysis shows reasons why this is true; fluctuations, small or big, introduce bigger variance in workload than what is naturally occurring. So, activities in production whether to optimize efficiency, to adjust for happenings affecting scheduled takt or due to production structural will, if not managed clever, introduce *muri* and *mura* for the forklifts operators. The environment in which the forklift operators are situated is uneven, unpredictable and at times overburdening them. From the lean waste perspective, logistics and production need to be viewed as interrelated organizational units, rather than isolated isles, when targeting new waste reduction projects.

7.2. Academic contribution

The thesis findings exemplify how waste, other than waste related to specific activities, can be identified in relation to and outside the shop floor. It exemplifies *muri* and *mura* wastes within internal logistics and material handling and discuss how these types can emerge.

The case company won the Swedish lean prize in 2010 and are evidently far into their lean transition. While production is controlled via the Heijunka boards, logistics is left to their own without considering improvement projects to mitigate or hamper the effect production fluctuations may have on logistics. Thus, the findings indicate how a company can be far into a lean transition despite overlooking obvious cross-functional benefits while still being successful in a lean and business perspective.

Essentially, the findings highlight why production and logistics cannot be viewed independently when striving to identify and reduce waste. If the cross-functional aspect is overlooked, waste reduction may sub-optimize towards whichever unit is in bias and the overall benefits might be hampered.

7.3. Future research

When considering the methodology, it is interesting how deployment of more advanced simulation software, like AutoMod and AutoStat would affect the findings.

It would be interesting to investigate what other support functions and if any, how these are affected fluctuations in production.

8. RECOMMENDATIONS TO AUTOLIV

In this chapter recommendations to Autoliv are given. The recommendations is divided into five main categorizes; information gathering, information sharing and cross functionality, decision making, constraints to rail management and product variants.

8.1. Information gathering

In general, information is essential to relate events and aspects to each other. At Autoliv, on this particular topic, information is lacking and experience rather than exhaustive information dominates decision making. Other than relating contemporary events, information is also required for standardization and process improvements. The Excel tool created provides estimation on the workload for the logistic department, but the information the tool provide can be improved within the following aspects:

- Find a way to *standardize forklift activities*, which will facilitate a more extensive time-study on the different activities performed by the forklift operators.
- The tool does not include the difference in gear takt time between EU and US products for production cells.
- Extend the tool to include *other logistics activities* closely related to the forklifts currently included. First choice would be goods reception- and finished goods forklifts and at a later stage also activities not normally included in the serial flow either per unit produced or as an overhead.

Furthermore, all BOM's do not include finished goods packaging consumption. Updating them would help when calculating logistics workload since consumption then can be related to takt time. Old or obsolete information may be misleading and the tool should be updated continuously in order to ensure its reliability.

8.2. Information sharing and cross functionality

At the current state, information is shared between production and the logistics department to a *very small extent*. Lack of information contributes to the bullwhip effect and the findings in chapter 5 and 6 suggest this is also a viable conclusion for the micro level within the plant itself. From the logistics point of view, the main priority would be to know which takt, or actual number of operators, each shift plans to produce with, in each production cell. Secondly production would need to know which, in terms of overburdening the forklifts, temporary combinations of production gears that are critical. The Excel tool, provided updated takt time and manning, is closing the first information gap. However, recommendation as to in between which production cells a staffing switch is more critical is required. Such recommendation or suggestions to constraint to Rail Management are made in section 8.4. An essential recommendation to Autoliv is to *extend the cross functionality* between production and logistics in order to hamper negative effects for logistics when production alone take decisions within the topic area.

8.3. Decision making

Furthermore, it is important to share the information the tool provides to the forklift operators and managers so they can alter decisions accordingly. The operators need information on a heads up operative day-to-day or hour-to-hour level. Managers need information on a strategic level to be able to make decisions regarding re-distribution of work tasks, staffing and to test new material flows. The Excel tool can be used when making decisions regarding new material flows and how a change in material flows will affect the logistics function. For instance, logistics impact should be included when making changes in production, developing new products thus arranging new material flows and finished goods packaging load sizes. For the operators, the information can be used to distribute unevenness between each other in order to help the ones with more work for the moment.

8.4. Constraints to Rail Management

The production gears often mismatch the contracted planned output and consequently measures for production to reach feasible efficiency is a logic concern. The rails were introduced to allow production to deviate from the planned schedule while still maintaining the queue and first-in-first-out flow. There are noticeable changes in workload among the forklifts for certain production cells; however the cell forklifts are within the 85% limit while Abhall and Chall are only within 100% for normative state (see Appendix I). Thus, even the small noticeable changes up and down between the production gears have impact on the workload among the forklifts and will at times overburden, affected forklifts. Rail management, when moving staff around between production cells to achieve efficient takt, is very similar to the gear mismatch but without the constraints to produce just over or under the contracted takt. Therefore, moving staff around will affect logistics in a similar way as the gear mismatch but with a significant effect in logistics workload and its dispersion among the forklifts. All forklifts, except SM23 and SM4, will for certain production cell staffing combinations overdraw the 85% limit and the Abhall and Chall forklifts will go over 100%. Therefore, the following recommendation regarding Rail Management and production cell staffing switches are given:

- If possible, switch manning between lines with similar logistics characteristics and essentially same logistics workload.
- Avoid switching within the AMG: s between the production halls. It is e.g. not recommended to change from SAB to PAB/DAB since this would distort the workload among the forklift while maintaining the same total staffing in production.
- The most radical change would be changing 5 operators from X14:2 to DCU3 and would increase the Chall forklifts workload with 15 min/hour.
- Evaluate if there are more than one option and change according to least logistics effect.

8.5. Product variant

Through the scenarios, product variants with particularly high workload are identified. Those product variants are listed in Table 7. The difference in minutes denotes the difference in workload for the product variation in relation to the leveled mix. Additional forklift work time stands for the percentage increase of the total work time the specific product variant causes (a full list of production cells and their effects for the product variant scenario is found in Appendix II).

Table 7: Product variants yielding particularly high logistics work load.

Forklift	Production cell	Article number	Difference (min)	Additional forklift work time
Total	DCU3	615643900-0	47,7	19,7%
Abhall	PAB10	618314600	6,2	13%
	DCU3	615643900-1	2,2	4,6%
	DAB12	604777800	1,3	2,7%
Chall	DCU3	615643900-0	47,6	87%
	X14-2	605749914	9	16%
USM1	DAB12	604777800	3,6	9,2%
	DAB11	607794100	1,0	2,5%
	PAB10	605188900	0,77	2,0%
SM1P	SAB11	608992700	4,9	16%
	SAB18	616656401	1,8	3,9%
SM23	IC15	6110276011	4,0	11%
	IC9	605094000	0,66	1,8%
	IC13	605094200	0,45	1,2%
SM4	X14-2	605749900	2,4	7,8%
	DCU3	615643900-0	2,0	6,4%
	SP2	6069352993	1,6	5,1%
	SP11	607942233	0,88	2,8%

It is recommended that when these product variants are produced that special attention is spent on information sharing among the operators especially for the product variant produced in the DCU3 production cell since it increases the demand for transportation with 87%. As a future recommendation regards to logistics characteristics should be taken when developing new product as that enables these variations to be mitigated.

8.6. Final conclusion

Each scenario, besides the Rail Management and gear mismatch, has the change to occur simultaneously. However, the probability for an extreme situation by each scenario is low and thus combinations off less significant effects are more likely to occur. Either way, logistics workload is dispersed or uneven if attention is not given to information sharing between production and logistics and to hamper the identified scenarios. The variation creates uncertainties, which in turn calls for overcapacity to cope with the fluctuations. In order to counteract and decrease the overcapacity, the variation needs to be removed.

9. REFERENCES

Autoliv. (2011b). *Fast Facts*. Retrieved 2011 йил 25-05 from Autoliv: http://www.autoliv.com/wps/wcm/connect/autoliv/Home/Who+We+Are/Fast%20Facts

Autoliv. (2011a). *History*. Retrieved 2011 йил 25-05 from Autoliv: http://www.autoliv.com/wps/wcm/connect/autoliv/Home/Who+We+Are/history/1990

Banks, J., Carson, J. S., Nelson, B. L., & Nicol, D. M. (2005). *Discrete-event system simulation* (4th Edition ed.). Upper Saddle River: Pearson Prentice Hall.

Baudin, M. (2002). *Lean Assembly: The nuts and bolts of making assembly operations flow*. New York: Productivity Press.

Baudin, M. (2004). *Lean Logistics.* New York: Productivity Press.

Cottyn, J., Govaert, T., & Van Landegham, H. (2008). Alternative line delivery strategies support a forklift free transition in a high product variety environment. *International Workshop on Harbor Maritime and Multimodal Logistics Modeling and Simulation (HMS 2008).* Campora S. Giovanni.

Gadde, L.-E. (2004). Activity Coordination and Resource combining in distribution networks - implications for relationship involvement and the relationship atomosphere. *Journal of Marketing Management , 20* (1-2), 157-184.

Gillham, B. (2000). *Case stud research methods.* London: Continuum.

Hartman, J. (2004). *Vetenskapligt tänkande.* Studentlitteratur AB.

Industrinyheterna. (2010, 10 06). *Autoliv vinnare av svenska leanpriset*. Retrieved 05 25, 2011, from Industrinyheterna: http://www.industrinyheterna.se/2010/10/autoliv-sverige-vinnare-av-svenska-leanpriset

Ivanov, D., & Sokolov, B. (2010). *Adative Supply Chain Management.* London: Springer-Verlag.

Johansson, E., & Johansson, M. I. (2006). Material supply systems design in product development projects. *International Journal of Operations & Production Management , 26* (4), pp. 371-393.

Jonsson, P., & Mattsson, S.-A. (2009). *Manufacturing, Planning and Control.* Maidenhead: McGraw-Hill Education.

Karlsson, C. (2008). *Researching operations Management.* London: Taylor & Francis Ltd.

Liker, J. K. (2004). *The Toyota Way: 14 Management Principles from the world's greatest manufacturer.* New York: McGraw-Hill.

Liker, J. K., & Meier, D. (2006). *The Toyota Way Fieldbook.* New York: McGraw-Hill.

Lumsden, K. (1998). *Logistikens grunder.* Lund: Studentlitteratur.

Mentzer, J. T., DeWitt, W., Keebler, J. S., Min, S., Nix, N. W., Smith, C. D., et al. (2001). Defining Supply Chain Management. *Journal of Business Logistics* .

Patel, R., & Davidsson, B. (2003). *Forskningsmetodikens grunder* (3rd Edition ed.). Lund: Studentlitteratur.

Schonberger, R. J. (2007). Japanese production management: An evolution - With mixed success. *Journal of Operations Management , Vol. 25* (No. 2), 403-419.

Skjoett-Larsen, T., Schary, P. B., Mikkola, J. H., & Kotzab, H. (2007). *Managing the Global Supply Chain.* Gylling, Denmark: Copenhagen Business School Press.

Svensson, G. (2003). The bullwhip effect in intra-organisational echelons. *International Journal of Physical distribution and Logistics Management* , 103-131.

Vollmann, T. E., Berry, W. L., & Whybark, C. D. (2005). *Manufacturing planning and control for supply chain management.* Boston: McGraw-Hill.

Yin, R. K. (2009). *Case study Research Design and Methods.* Thousand Oaks: Sage Publications Inc.

APPENDIX I

Appendix I contain all data and results relating to the normative state scenario. First, all data is presented in charts for each production AMG and secondly a table containing workload, in minutes per hour, for each production cell and forklift.

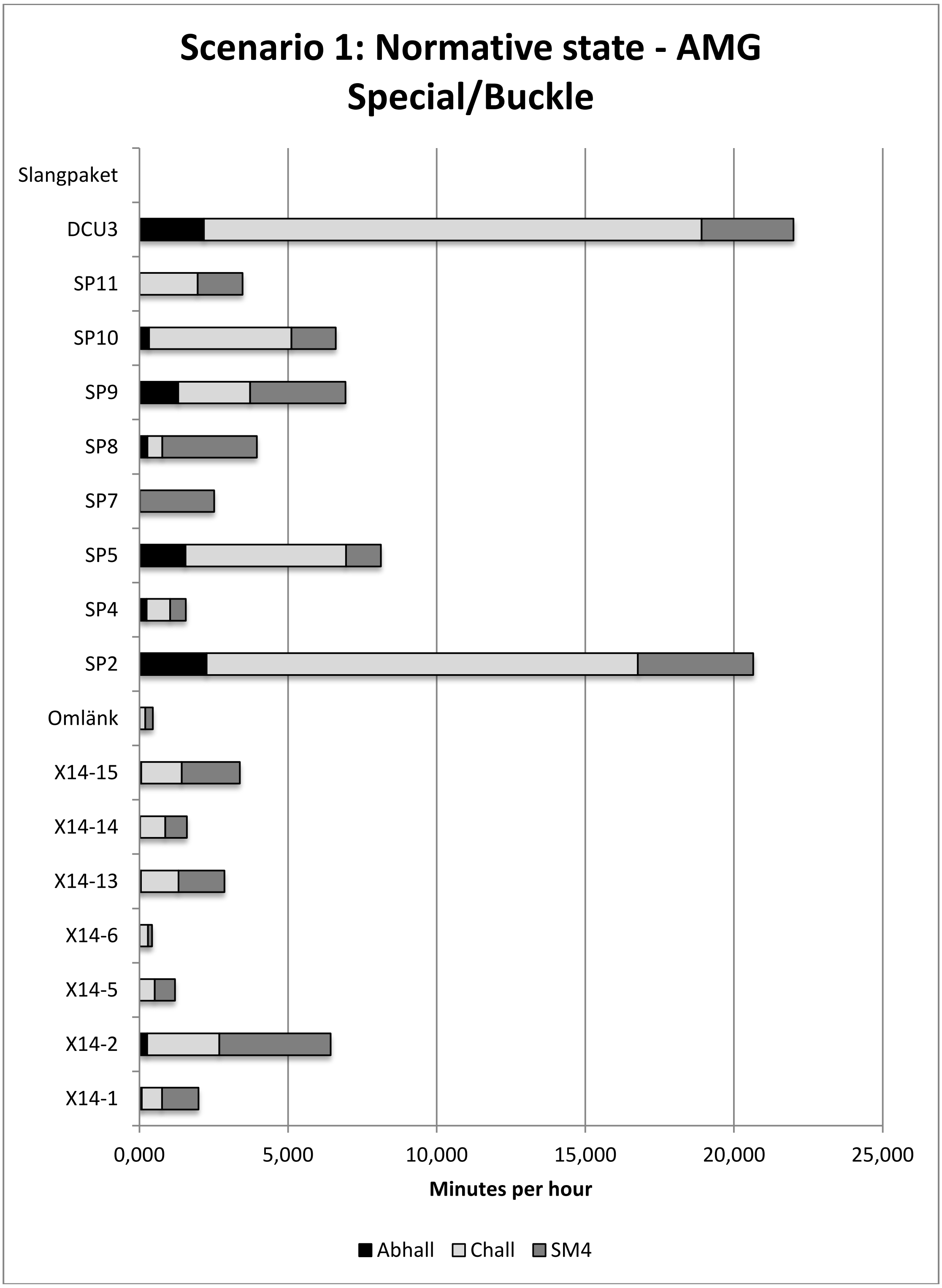


Figure 1-1: Aggregated workload for production cells in AMG Special/Buckle per each specific forklift operator.

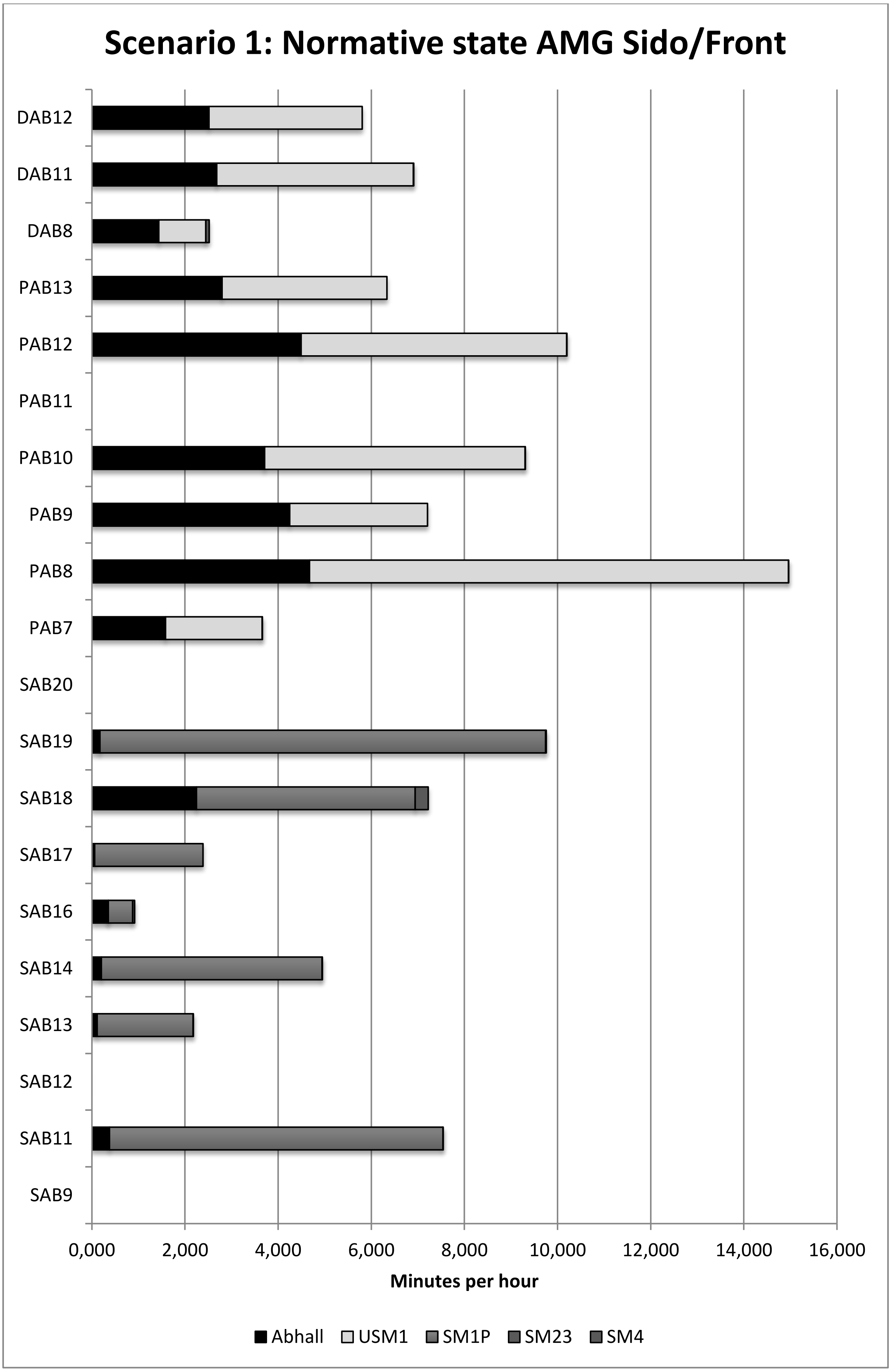


Figure 1-2: Aggregated workload for production cells in AMG Sido/Front per each specific forklift operator.

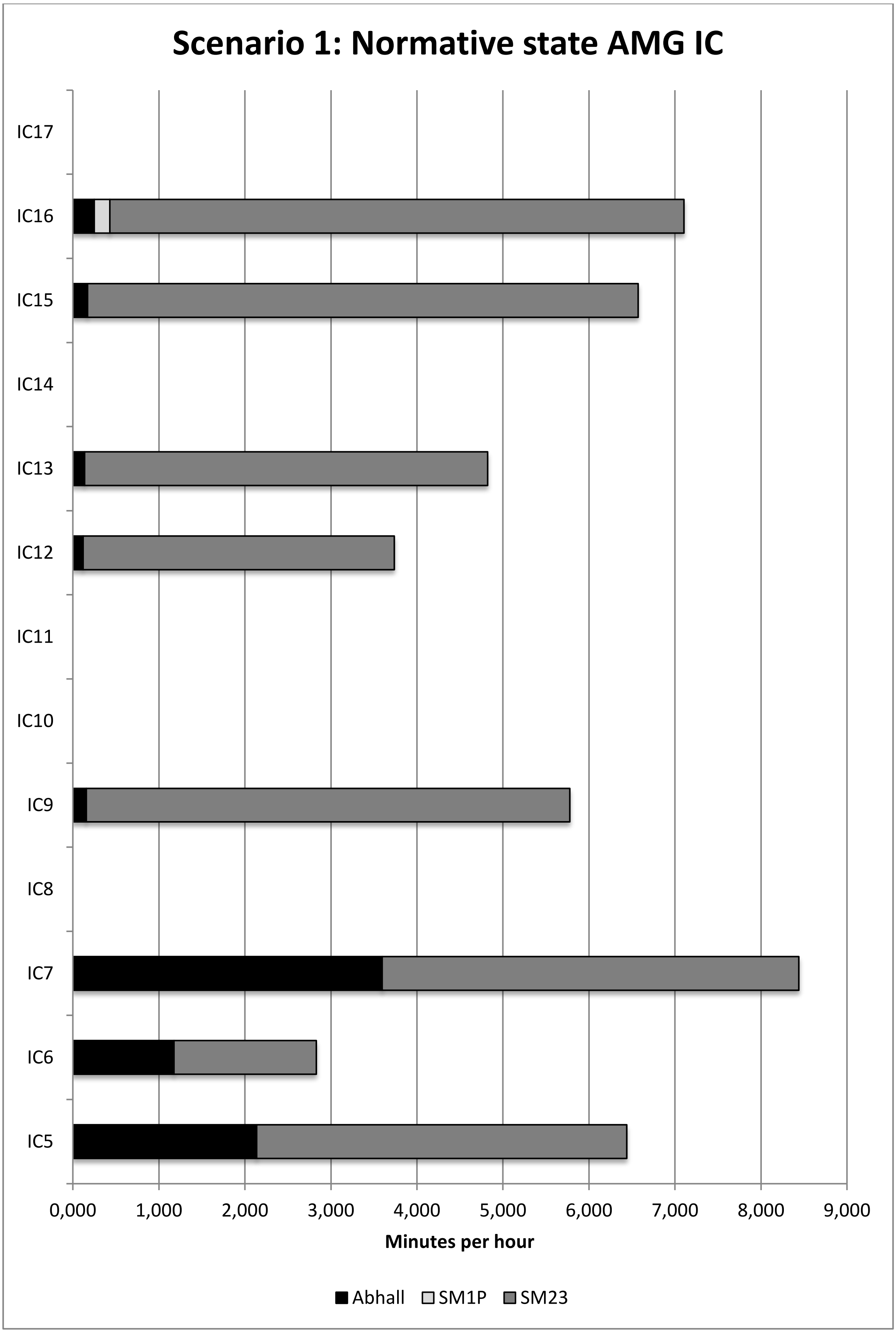


Figure 1-3: Aggregated workload for production cells in AMG IC per each specific forklift operator.

Table 1-1: Workload per production cell for each forklift operator.

	Abhall	Chall	USM1	SM1P	SM23	SM4
IC5	2,139				4,302	
IC6	1,176				1,657	
IC7	3,598				4,845	
IC8						
IC9	0,158				5,621	
IC10						
IC11						
IC12	0,120				3,619	
IC13	0,138				4,686	
IC14						
IC15	0,172				6,402	
IC16	0,248			0,183	6,675	
IC17						
SAB9						
SAB11	0,378			7,161	0,005	
SAB12						
SAB13	0,114			2,060	0,001	
SAB14	0,204			4,739	0,008	
SAB16	0,352		0,002	0,523		0,042
SAB17	0,060			2,327		
SAB18	2,246			4,697		0,280
SAB19	0,173			9,569	0,015	
SAB20						
PAB7	1,582		2,076		0,001	
PAB8	4,673		10,285		0,002	
PAB9	4,248		2,959			
PAB10	3,710		5,594		0,001	
PAB11						
PAB12	4,494		5,702		0,001	
PAB13	2,796		3,541			
DAB8	1,437		1,010			0,073
DAB11	2,682		4,222			0,008
DAB12	2,515		3,290			
X14-1	0,087	0,679				1,225
X14-2	0,270	2,418				3,748
X14-5	0,002	0,517				0,681
X14-6	0,013	0,279				0,139
X14-13	0,059	1,257				1,548
X14-14	0,034	0,839				0,732
X14-15	0,063	1,365				1,959
Omlänk	0,012	0,191				0,253
SP2	2,265	14,509				3,880
SP4	0,247	0,795				0,526
SP5	1,554	5,398				1,177
SP7	0,023					2,495
SP8	0,277	0,501				3,175
SP9	1,314	2,415				3,204
SP10	0,327	4,791				1,491
SP11	0,014	1,950				1,513
DCU3	2,177	16,736				3,090
Slangpaket						
Total	**48,150**	**54,640**	**38,681**	**31,260**	**37,839**	**31,237**

APPENDIX II

Appendix II contains all data and results related to the product variant scenario. First, table 2-1 displays workload, in minutes per hour, for each production cell and forklift both for min, normal and max. Later charts for each production AMG and their affect on variance in the total transportation demand are included and finally so are also charts per each forklift operator.

Table 2-1: A summary of workload per production cell for the total demand and the production hall forklifts.

	Total demand			Abhall			Chall		
	Min	Normal	Max	Min	Normal	Max	Min	Normal	Max
IC5	4,780	6,441	6,601	2,066	2,139	2,146			
IC6	2,804	2,832	2,862	1,176	1,176	1,176			
IC7	8,059	8,443	9,132	3,328	3,598	4,084			
IC8									
IC9	4,613	5,779	6,455	0,138	0,158	0,170			
IC10									
IC11									
IC12	3,738	3,738	3,738	0,120	0,120	0,120			
IC13	4,034	4,824	5,285	0,121	0,138	0,148			
IC14									
IC15	5,794	6,573	10,569	0,176	0,172	0,176			
IC16	6,903	7,106	7,584	0,231	0,248	0,288			
IC17									
SAB9									
SAB11	7,382	7,545	12,463	0,378	0,378	0,378			
SAB12									
SAB13	2,176	2,176	2,176	0,114	0,114	0,114			
SAB14	4,951	4,951	4,951	0,204	0,204	0,204			
SAB16	0,918	0,918	0,918	0,352	0,352	0,352			
SAB17	2,387	2,387	2,387	0,060	0,060	0,060			
SAB18	5,591	7,223	8,855	2,103	2,246	2,389			
SAB19	9,758	9,758	9,758	0,173	0,173	0,173			
SAB20									
PAB7	3,645	3,658	3,692	1,582	1,582	1,582			
PAB8	14,960	14,960	14,960	4,673	4,673	4,673			
PAB9	6,896	7,208	7,548	4,210	4,248	4,284			
PAB10	8,528	9,304	15,583	2,992	3,710	9,901			
PAB11									
PAB12	10,066	10,198	10,819	4,490	4,494	4,514			
PAB13	5,513	6,336	7,640	2,273	2,796	3,486			
DAB8	2,505	2,520	2,558	1,429	1,437	1,460			
DAB11	6,863	6,912	8,690	2,667	2,682	3,205			
DAB12	4,530	5,805	10,688	2,066	2,515	3,828			
X14-1	1,991	1,991	1,991	0,087	0,087	0,087	0,679	0,679	0,679
X14-2	5,768	6,436	15,983	0,150	0,270	0,285	2,316	2,418	11,307

	Total demand			**Abhall**			**Chall**		
	Min	Normal	Max	Min	Normal	Max	Min	Normal	Max
X14-5	1,185	1,199	1,389	0,000	0,002	0,023	0,514	0,517	0,555
X14-6	0,430	0,430	0,430	0,013	0,013	0,013	0,279	0,279	0,279
X14-13	2,174	2,864	3,949	0,045	0,059	0,087	0,778	1,257	2,692
X14-14	1,590	1,605	1,618	0,033	0,034	0,039	0,839	0,839	0,839
X14-15	2,764	3,386	4,981	0,034	0,063	0,103	1,138	1,365	2,542
Omlänk	0,457	0,457	0,457	0,012	0,012	0,012	0,191	0,191	0,191
SP2	16,431	20,654	24,873	2,180	2,265	2,734	12,244	14,509	16,663
SP4	1,569	1,569	1,569	0,247	0,247	0,247	0,795	0,795	0,795
SP5	7,741	8,129	8,162	1,330	1,554	1,573	5,398	5,398	5,398
SP7	2,449	2,518	2,525	0,021	0,023	0,023			
SP8	3,952	3,952	3,952	0,277	0,277	0,277	0,501	0,501	0,501
SP9	6,933	6,933	6,933	1,314	1,314	1,314	2,415	2,415	2,415
SP10	6,514	6,609	6,706	0,327	0,327	0,327	4,075	4,791	5,523
SP11	3,287	3,477	3,667		0,014		1,261	1,95	2,682
DCU3	19,747	22,002	69,693	0,162	2,177	4,376	14,525	16,736	64,305
Slangpaket									
Total	222,376	241,806	334,789	43,353	48,151	60,432	47,949	54,640	117,366

Table 2-2: Workload summary per production cell for the work cell forklifts USM1 and SM1P.

	USM1			SM1P		
	Min	Normal	Max	Min	Normal	Max
IC5						
IC6						
IC7						
IC8						
IC9						
IC10						
IC11						
IC12						
IC13						
IC14						
IC15						
IC16					0,183	0,616
IC17						
SAB9						
SAB11				6,999	7,161	12,079
SAB12						
SAB13				2,060	2,060	2,060
SAB14				4,739	4,739	4,739
SAB16		0,002	0,002	0,523	0,523	0,523
SAB17				2,327	2,327	2,327
SAB18				3,487	4,697	5,906
SAB19				9,569	9,569	9,569
SAB20						

	USM1			**SM1P**		
	Min	Normal	Max	Min	Normal	Max
PAB7	2,063	2,076	2,110			
PAB8	10,285	10,285	10,285			
PAB9	2,613	2,959	3,338			
PAB10	5,465	5,594	6,364			
PAB11						
PAB12	5,575	5,702	6,304			
PAB13	3,24	3,541	4,154			
DAB8	0,989	1,01	1,025			
DAB11	4,196	4,222	5,183			
DAB12	2,321	3,29	6,861			
X14-1						
X14-2						
X14-5						
X14-6						
X14-13						
X14-14						
X14-15						
Omlänk						
SP2						
SP4						
SP5						
SP7						
SP8						
SP9						
SP10						
SP11						
DCU3						
Slangpaket						
Total	36,746	38,681	45,623	29,705	31,259	37,820

Table 2-3: Summary of workload per production cell for the work cell forklifts SM23 and SM4.

	SM23			SM4		
	Min	Normal	Max	Min	Normal	Max
IC5	2,714	4,302	4,455			
IC6	1,628	1,657	1,686			
IC7	4,731	4,845	5,049			
IC8						
IC9	4,475	5,621	6,286			
IC10						
IC11						
IC12	3,619	3,619	3,619			
IC13	3,914	4,686	5,136			
IC14						
IC15	5,618	6,402	10,420			

	SM23			SM4		
	Min	Normal	Max	Min	Normal	Max
IC16	6,672	6,675	6,680			
IC17						
SAB9						
SAB11	0,005	0,005	0,005			
SAB12						
SAB13	0,001	0,001	0,001			
SAB14	0,008	0,008	0,008			
SAB16				0,042	0,042	0,042
SAB17						
SAB18					0,280	0,560
SAB19	0,015	0,015	0,015			
SAB20						
PAB7	0,001	0,001	0,001			
PAB8	0,002	0,002	0,002			
PAB9						
PAB10		0,001				
PAB11						
PAB12	0,001	0,001	0,001			
PAB13						
DAB8				0,073	0,073	0,073
DAB11					0,008	0,302
DAB12						
X14-1				1,225	1,225	1,225
X14-2				3,210	3,748	6,166
X14-5				0,671	0,681	0,812
X14-6				0,139	0,139	0,139
X14-13				0,870	1,548	1,52
X14-14				0,718	0,732	0,746
X14-15				1,143	1,959	2,375
Omlänk				0,253	0,253	0,253
SP2				2,355	3,880	5,476
SP4				0,526	0,526	0,526
SP5				1,012	1,177	1,191
SP7				2,429	2,495	2,501
SP8				3,175	3,175	3,175
SP9				3,204	3,204	3,204
SP10				0,856	1,491	2,112
SP11				0,780	1,513	2,392
DCU3				3,023	3,090	5,086
Slangpaket						
Total	33,403	37,841	43,363	25,703	31,239	39,875

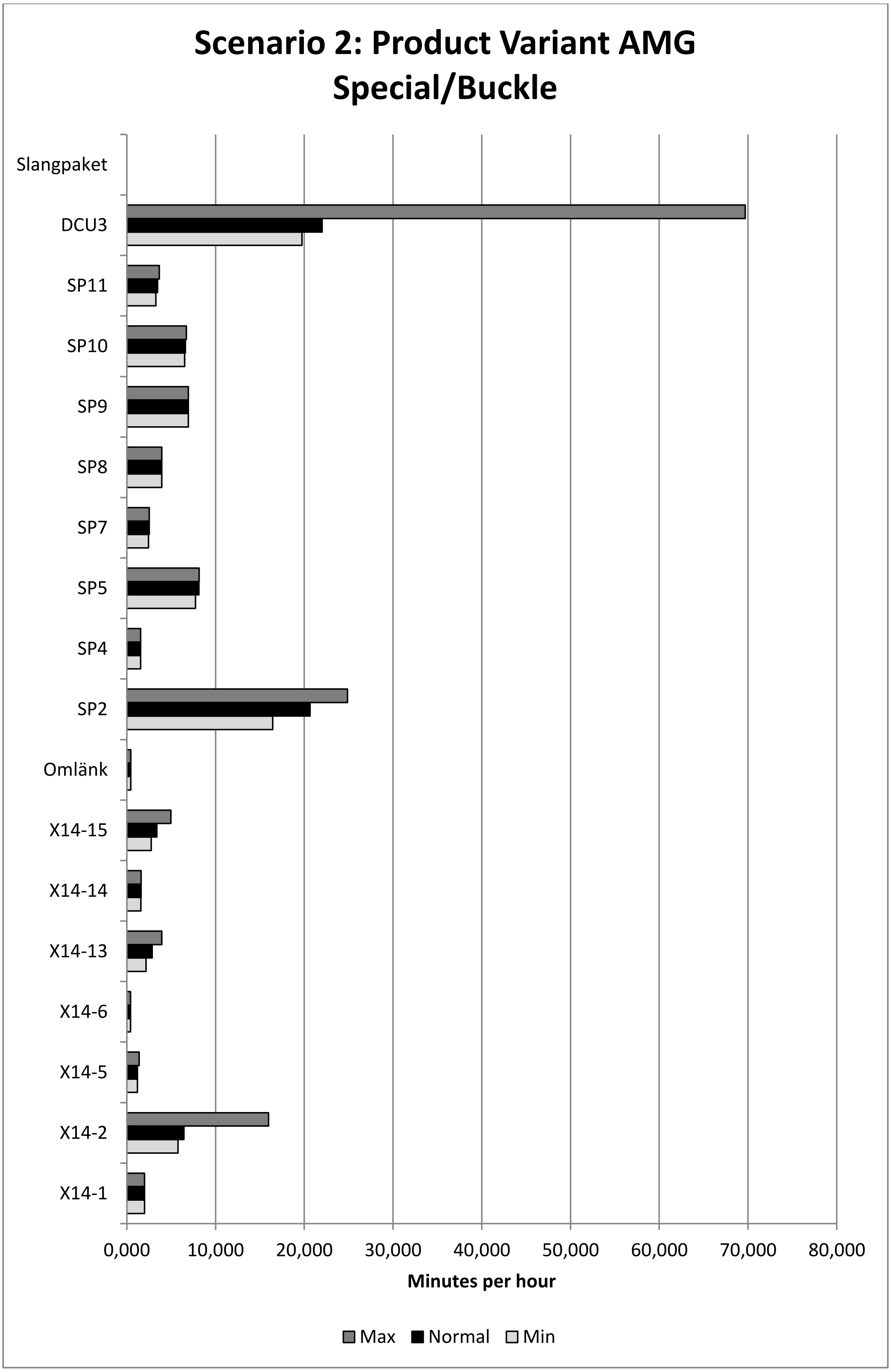


Figure 2-1: Aggregated workload for production cells in AMG Special/Buckle for the total transport demand in the product variant scenario.

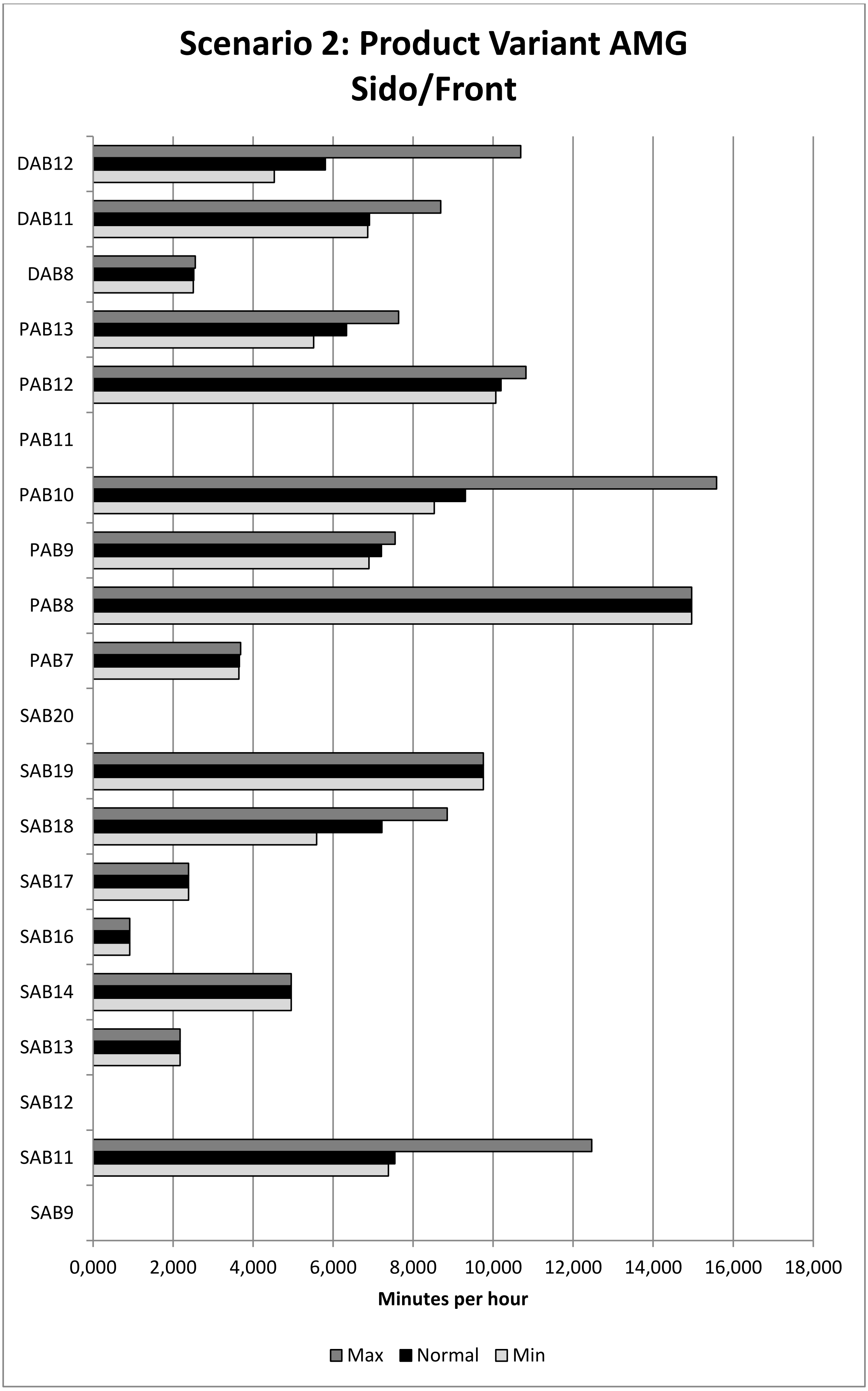


Figure 2-2: Aggregated workload for production cells in AMG Sido/Front, for the total transport demand in the product variant scenario.

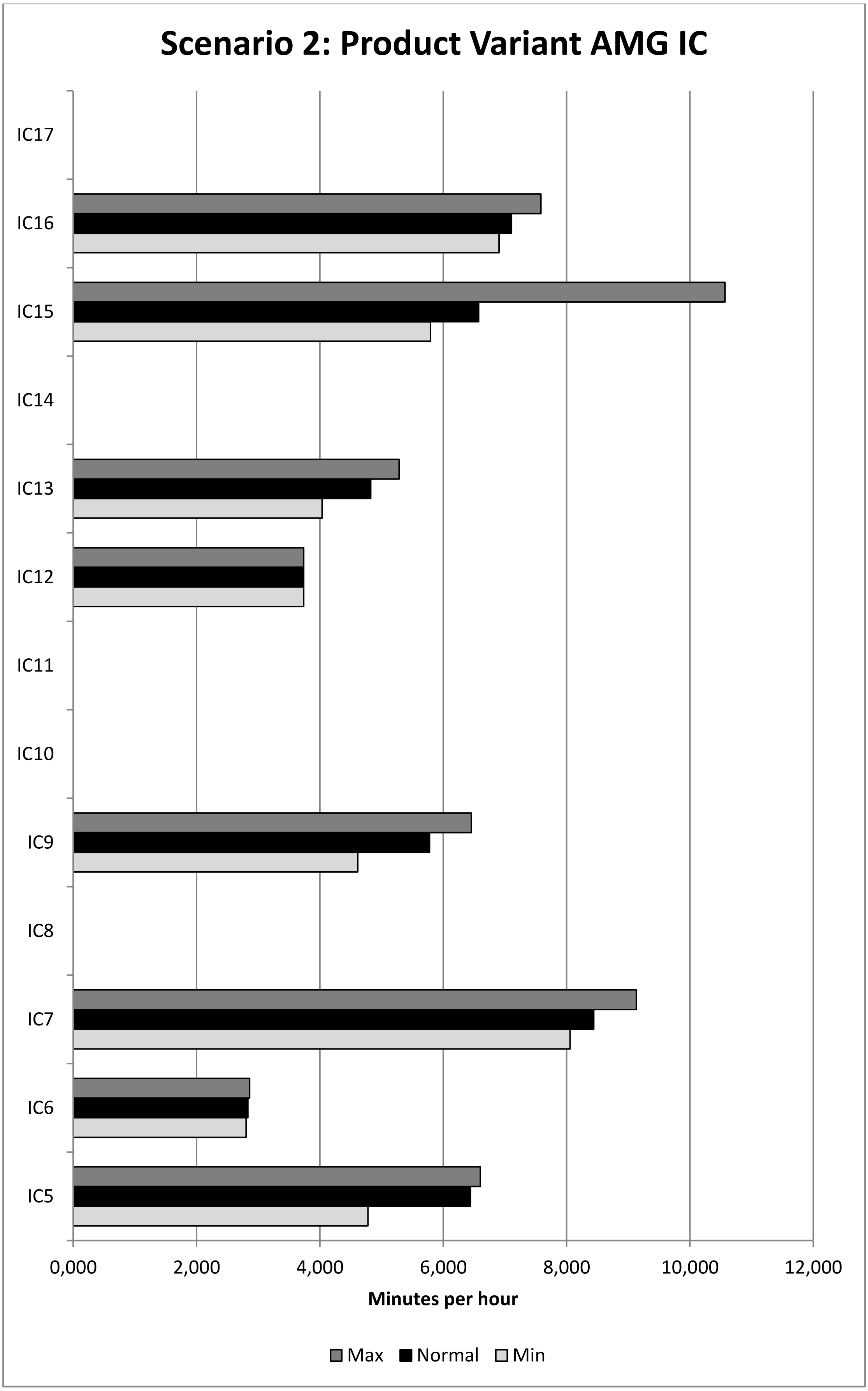


Figure 2-3: Aggregated workload for production cells in AMG IC, for the total transport demand in the product variant scenario.

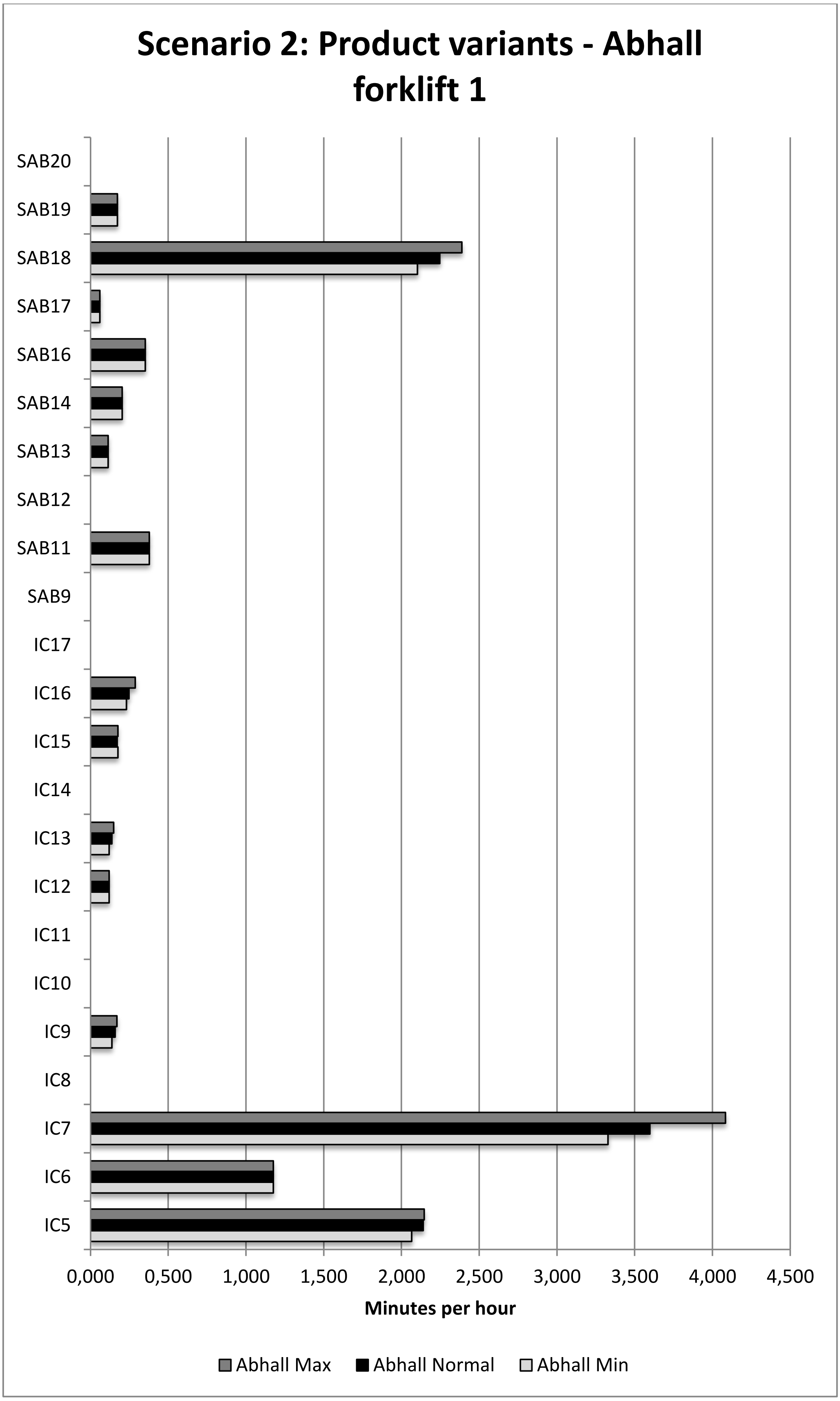


Figure 2-4: Illustration of aggregated workload for production cells IC and SAB for Abhall forklift in the product variant scenario.

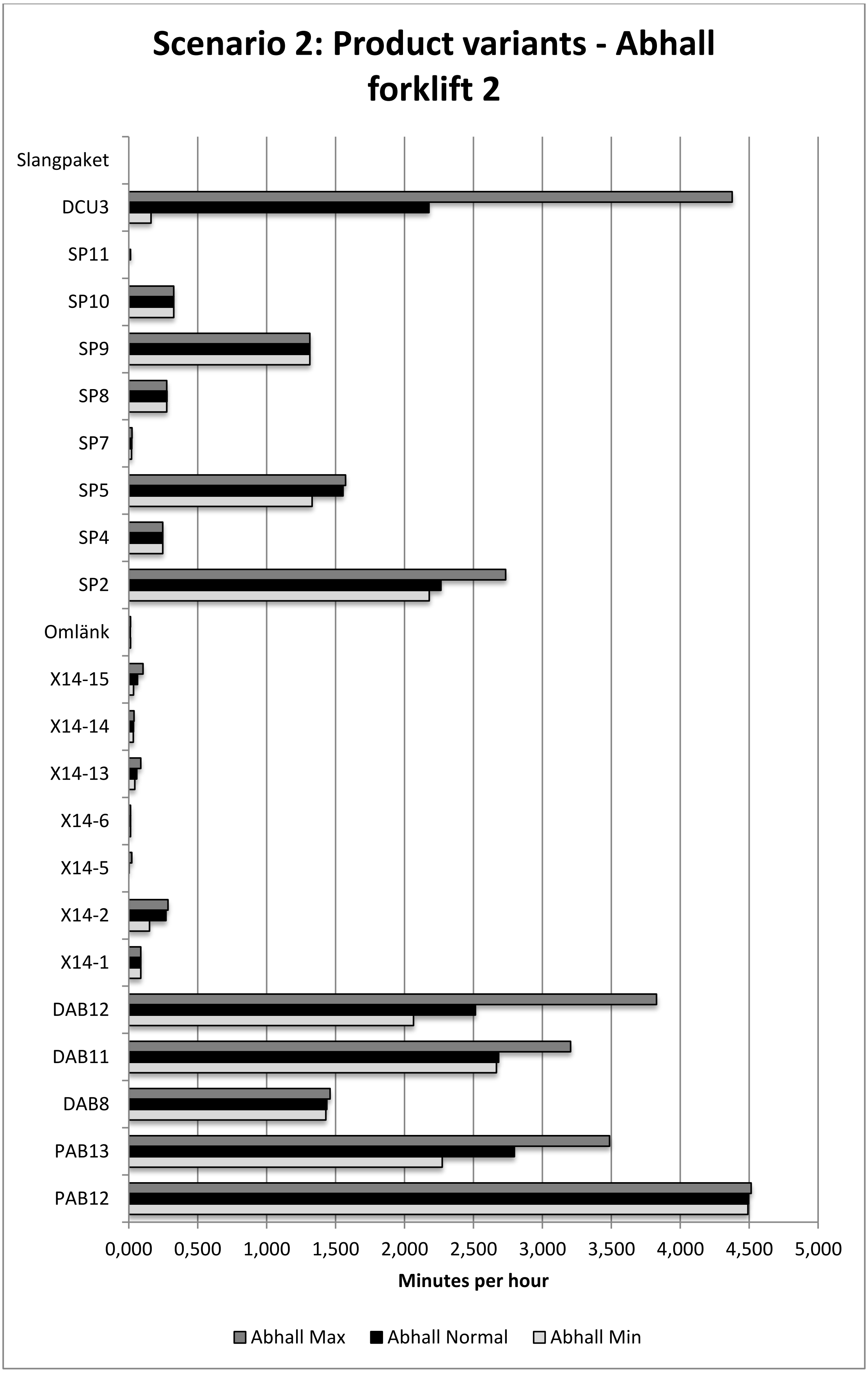


Figure 2-5: Illustration of aggregated workload for production cells Special, Buckle and DAB/PAB for Abhall forklift in the product variant scenario.

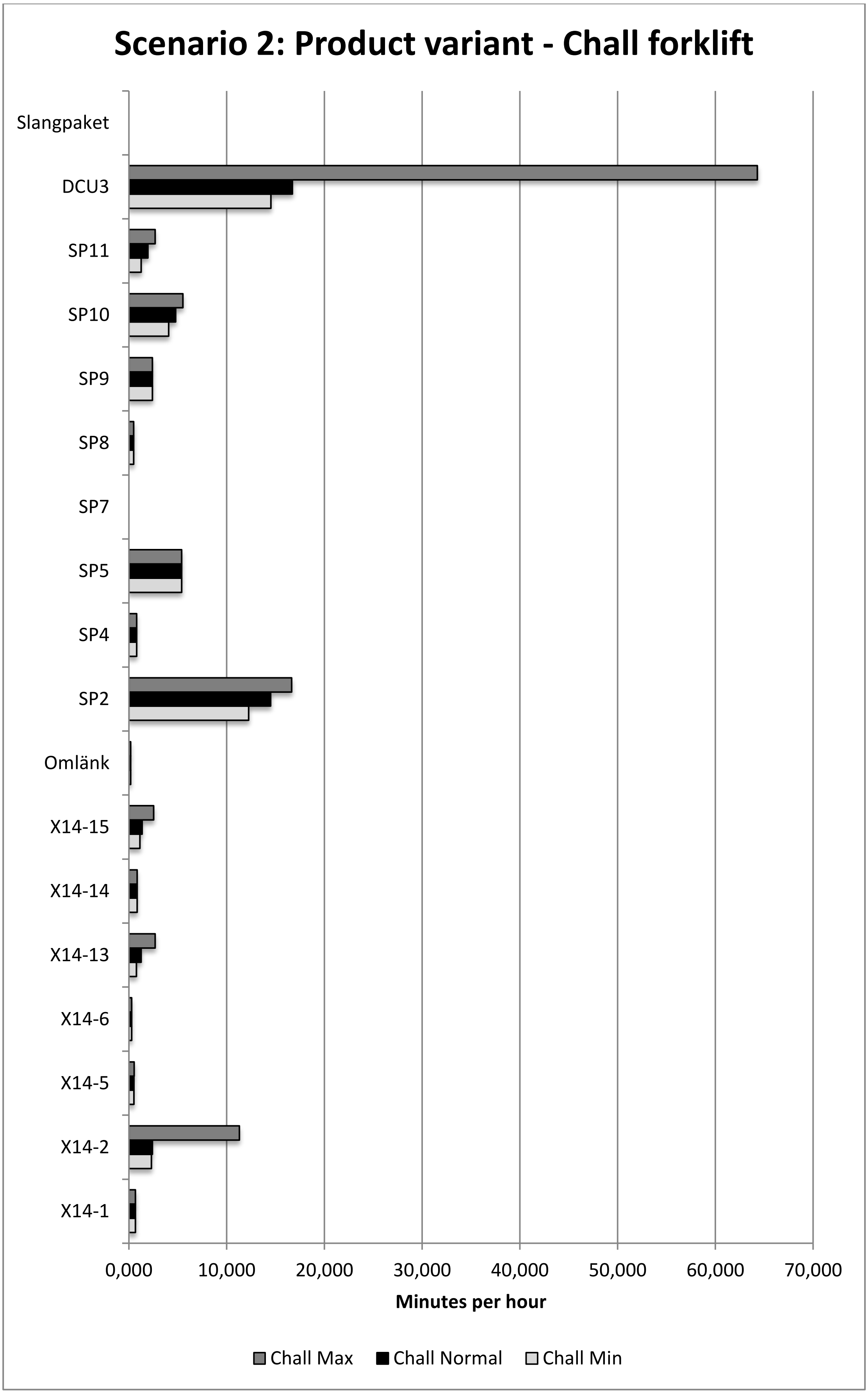


Figure 2-6: Illustration of aggregated workload for production cells affecting the Chall forklift operator in the product variant scenario.

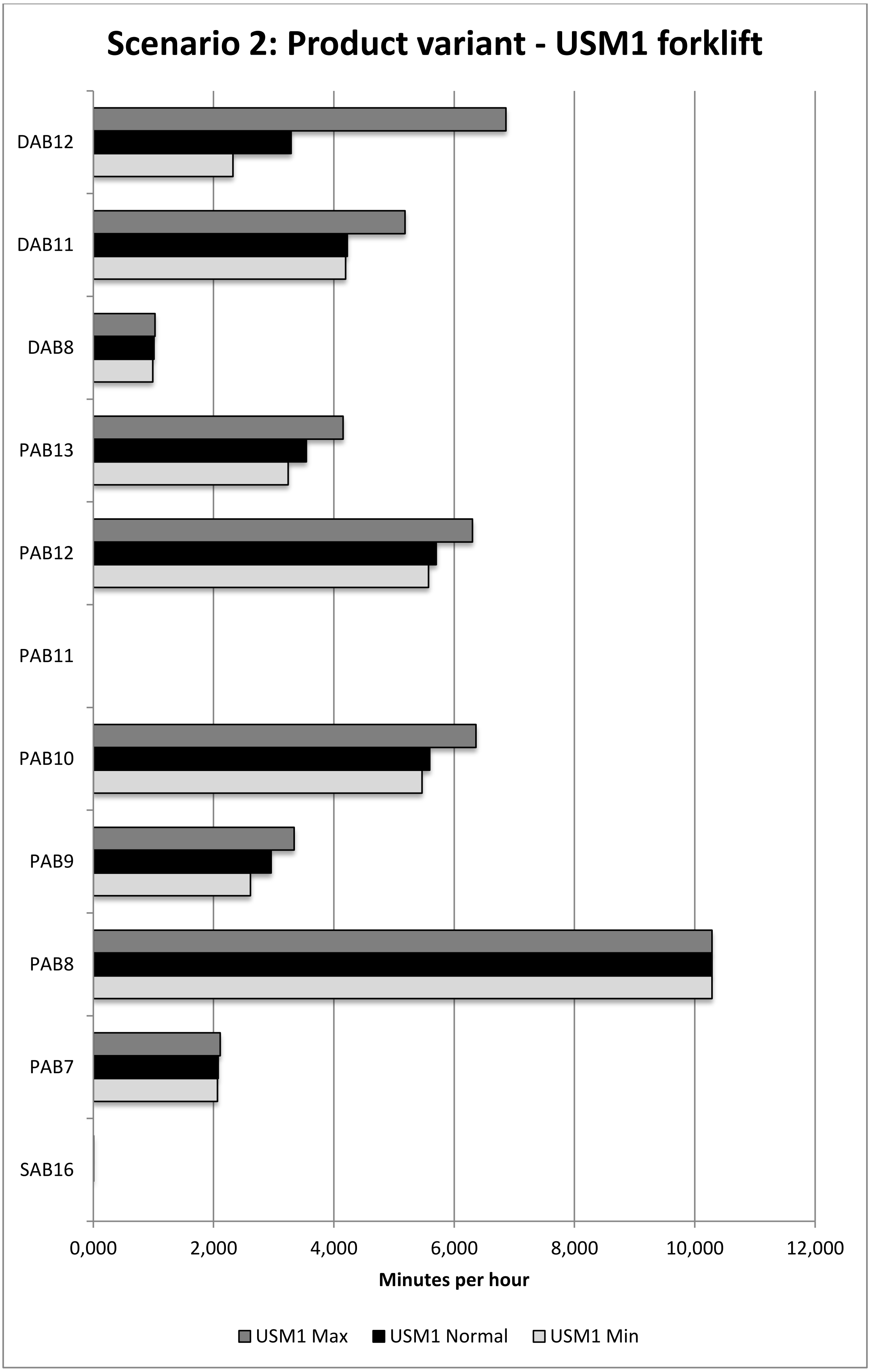


Figure 2-7: Aggregated workload for production cells affecting the USM1 forklift operator in the product variant scenario.

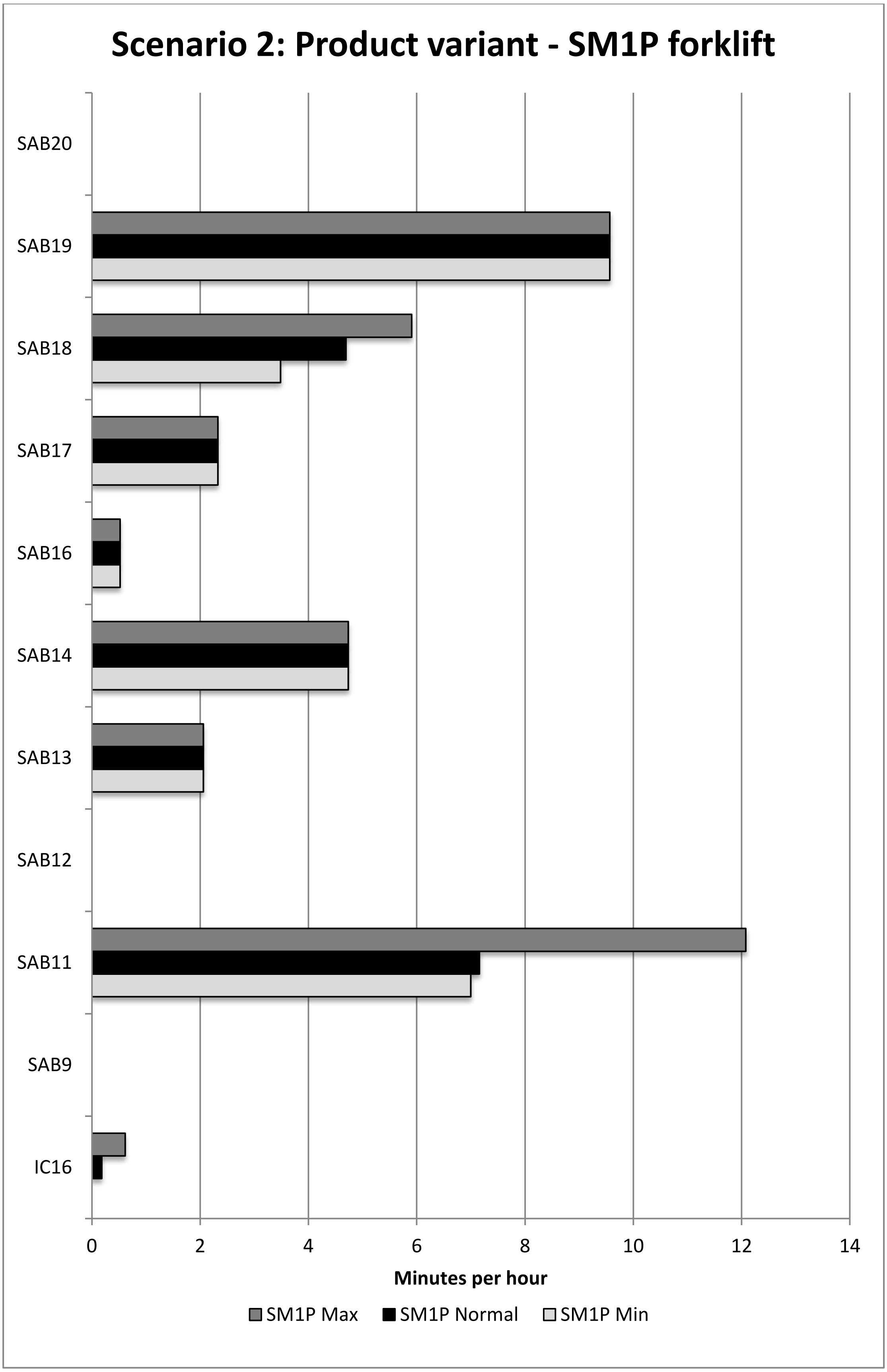


Figure 2-8: Aggregated workload for production cells affecting the SM1P forklift operator in the product variant scenario.

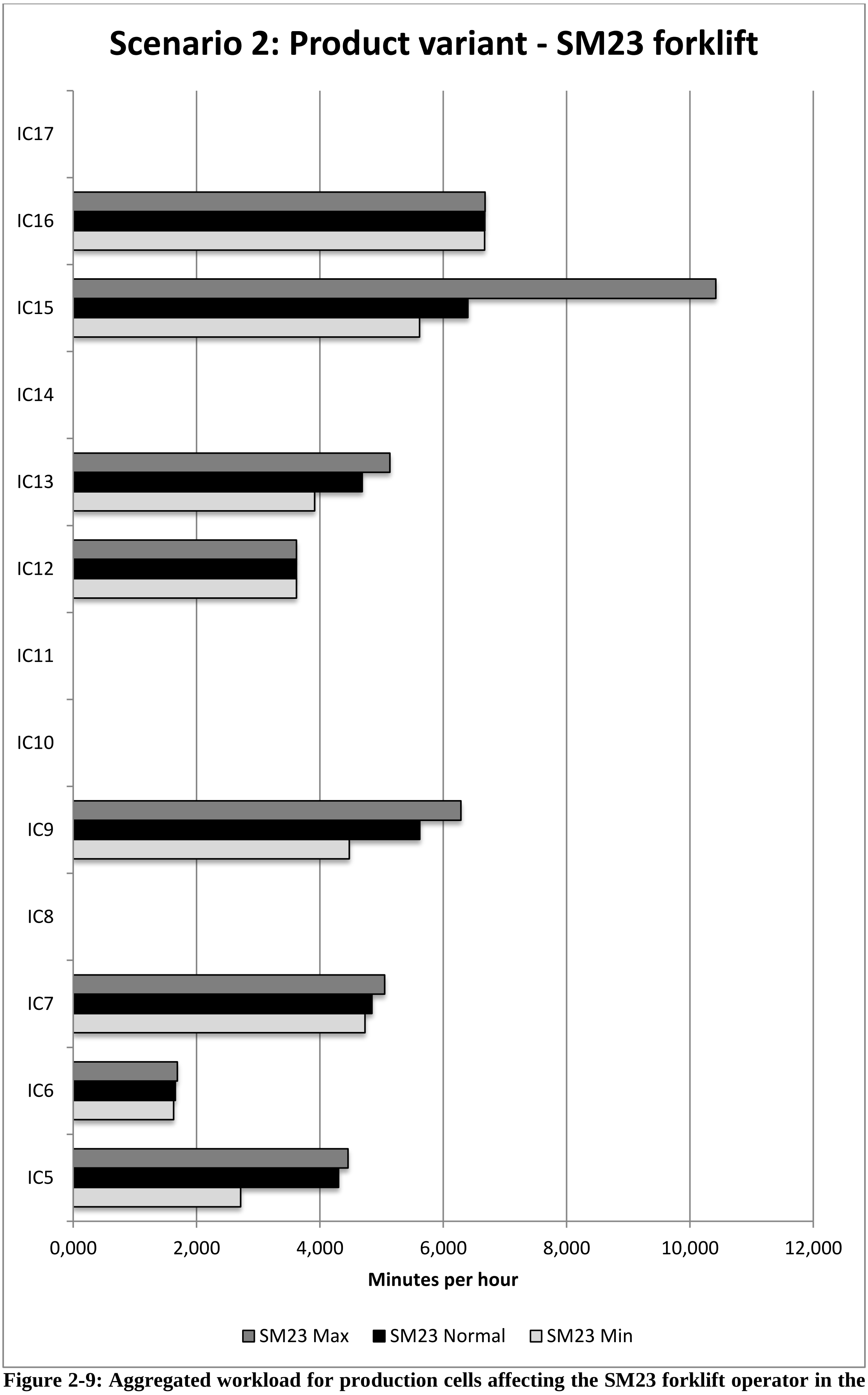


Figure 2-9: Aggregated workload for production cells affecting the SM23 forklift operator in the product variant scenario.

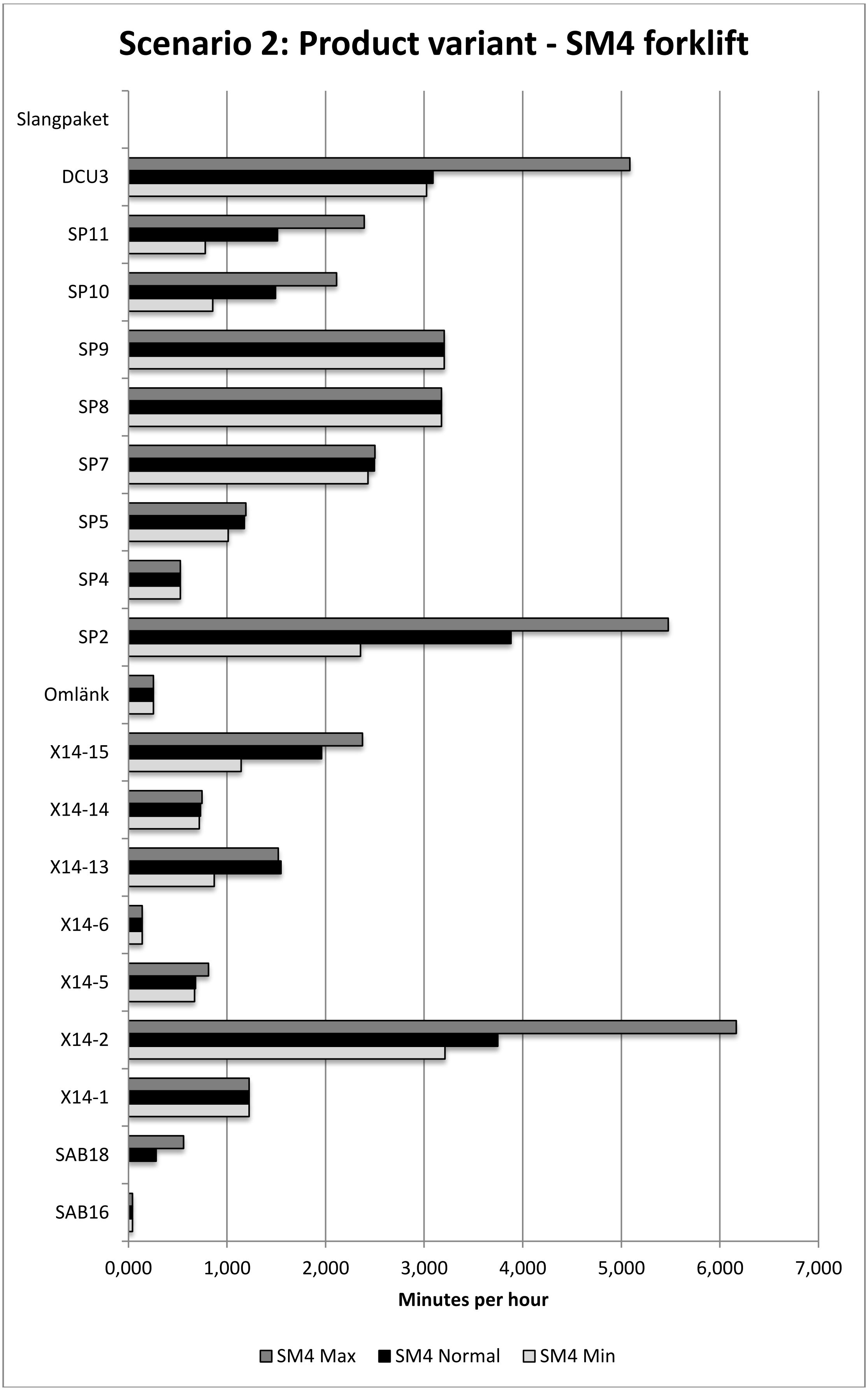


Figure 2-10: Aggregated workload for production cells affecting the SM4 forklift operator in the product variant scenario.

APPENDIX III

Appendix III contains all data and results in relation to the gear mismatch scenario. First tables contain workload per operator dependant on production cell and gear. Finally, workload in minutes per hour for each production cell and forklift is displayed both for min, normal and max.

Table 3-1: Workload per production cell and production gear for the total demand.

	Total demand								
	1	2	3	4	5	6	7	8	9
IC5					0,913		0,917		0,795
IC6	2,575	2,575	2,747						
IC7				1,290		1,290		1,290	
IC8	1,268								
IC9	1,567	1,371	1,469	1,420	1,391				
IC10	1,477	1,477	1,477	1,329					
IC11									
IC12	1,193	1,392	1,326						
IC13	1,496	1,309	1,402	1,356					
IC14	2,225	2,225							
IC15			2,151	2,305					
IC16			2,237	2,058					
IC17									
SAB9	2,649	2,649							
SAB11	7,545								
SAB12	1,895	1,640							
SAB13	3,709								
SAB14	3,380	3,380							
SAB16	3,139	2,906							
SAB17	2,010	2,010	2,010						
SAB18	1,848	1,883	1,712	1,883					
SAB19	5,260	6,904							
SAB20	2,179	1,383							
PAB7	4,119	4,119							
PAB8	5,616	7,300	5,616						
PAB9	5,162	4,964							
PAB10	4,019	5,024	4,555						
PAB11	1,679	1,679	1,455	1,427					
PAB12	4,343	4,343	4,054						
PAB13		2,361	2,405						
DAB8	2,863	2,863							
DAB11	1,893	1,922	1,721	1,721					
DAB12	4,576	3,687							
X14-1									
X14-2		1,194	1,326	1,318	1,333				
X14-5	2,159								
X14-6	1,100	1,100	0,978						
X14-13	1,742	1,742							
X14-14	2,021								
X14-15	1,499	1,568	1,590						
Omlänk	3,238								
SP2		5,483		5,026	4,533				
SP4	2,168								
SP5	2,227	2,413	2,475	2,506					
SP7	1,085	1,194	1,158	1,194					
SP8	1,520	1,520	1,520	1,482					

	Total demand								
	1	2	3	4	5	6	7	8	9
SP9	3,537	3,537							
SP10	7,184								
SP11	3,745								
DCU3	5,111	5,060	4,634	5,060	4,702	4,412			
Slangpaket									

Table 3-2: Workload per production cell and production gear for the Abhall forklift.

	Abhall								
	1	2	3	4	5	6	7	8	9
IC5					0,303		0,304		0,264
IC6	1,069	1,069	1,140						
IC7				0,550		0,550		0,550	
IC8	0,578								
IC9			0,040	0,039					
IC10	0,560	0,560	0,560	0,504					
IC11									
IC12			0,043						
IC13			0,040	0,039					
IC14	1,652	1,652							
IC15			0,056	0,060					
IC16			0,078	0,072					
IC17									
SAB9	0,092	0,092							
SAB11	0,378								
SAB12	0,891	0,771							
SAB13	0,195								
SAB14	0,139	0,139							
SAB16	1,202	1,113							
SAB17	0,051	0,051	0,051						
SAB18	0,575	0,585	0,532	0,585					
SAB19	0,094	0,123							
SAB20	0,107	0,068							
PAB7	1,781	1,781							
PAB8	1,754	2,281	1,754						
PAB9	3,043	2,926							
PAB10	1,603	2,003	1,816						
PAB11	0,699	0,699	0,606	0,594					
PAB12	1,914	1,914	1,786						
PAB13		1,042	1,061						
DAB8	1,633	1,633							
DAB11	0,734	0,745	0,668	0,668					
DAB12	1,983	1,597							
X14-1									
X14-2		0,050	0,056	0,055	0,056				
X14-5	0,003								
X14-6	0,032	0,032	0,029						
X14-13	0,036	0,036							
X14-14	0,042								
X14-15	0,028	0,029	0,030						
Omlänk	0,087								
SP2		0,601		0,551	0,497				
SP4	0,342								
SP5	0,426	0,461	0,473	0,479					
SP7	0,010	0,011	0,011	0,011					
SP8	0,106	0,106	0,106	0,104					

	Abhall								
	1	2	3	4	5	6	7	8	9
SP9	0,670	0,670							
SP10	0,356								
SP11	0,015								
DCU3	0,506	0,501	0,458	0,501	0,465	0,436			
Slangpaket									

Table 3-3: Workload per production cell and production gear for the Chall forklift.

	Chall								
	1	2	3	4	5	6	7	8	9
X14-1									
X14-2		0,449	0,498	0,495	0,501				
X14-5	0,930								
X14-6	0,713	0,713	0,634						
X14-13	0,765	0,765							
X14-14	1,057								
X14-15	0,604	0,632	0,641						
Omlänk	1,355								
SP2		3,852		3,531	3,184				
SP4	1,099								
SP5	1,479	1,602	1,643	1,664					
SP7									
SP8	0,193	0,193	0,193	0,188					
SP9	1,232	1,232							
SP10	5,207								
SP11	2,100								
DCU3	3,888	3,849	3,525	3,849	3,577	3,356			
Slangpaket									

Table 3-4: Workload per production cell and production gear for the USM1 forklift.

	USM1								
	1	2	3	4	5	6	7	8	9
SAB16	0,006	0,006							
PAB7	2,338	2,338							
PAB8	3,861	5,019	3,861						
PAB9	2,119	2,038							
PAB10	2,416	3,020	2,738						
PAB11	0,980	0,980	0,850	0,833					
PAB12	2,429	2,429	2,267						
PAB13		1,319	1,344						
DAB8	1,148	1,148							
DAB11	1,156	1,174	1,051	1,051					
DAB12	2,594	2,089							

Table 3-5: Workload per production cell and production gear for the SM1P forklift.

	SM1P								
	1	2	3	4	5	6	7	8	9
SAB9	1,820	1,820							
SAB11	7,161								
SAB12	0,360	0,311							
SAB13	3,512								
SAB14	3,235	3,235							
SAB16	1,788	1,655							
SAB17	1,959	1,959	1,959						
SAB18	1,202	1,224	1,113	1,224					
SAB19	5,159	6,771							
SAB20	1,935	1,228							

Table 3-6: Workload per production cell and production gear for the SM23 forklift.

	SM23								
	1	2	3	4	5	6	7	8	9
IC5					0,610		0,612		0,531
IC6	1,506	1,506	1,607						
IC7				0,740		0,740		0,740	
IC8	0,689								
IC9	1,524	1,334	1,429	1,381	1,353				
IC10	0,917	0,917	0,917	0,825					
IC11									
IC12	1,155	1,347	1,283						
IC13	1,453	1,271	1,362	1,317					
IC14	0,573	0,573							
IC15			2,095	2,245					
IC16			2,102	1,933					
IC17									
SAB9	0,737	0,737							
SAB11	0,005								
SAB12	0,644	0,557							
SAB13	0,002								
SAB14	0,005	0,005							
SAB16									
SAB17									
SAB18									
SAB19	0,008	0,011							
SAB20									
PAB7	0,001	0,001							
PAB8	0,001	0,001	0,001						
PAB9									
PAB10									
PAB11									
PAB12	0,001	0,001	0,001						

Table 3-7: Workload per production cell and production gear for the SM4 forklift.

	SM4								
	1	2	3	4	5	6	7	8	9
SAB16	0,143	0,133							
SAB17									
SAB18	0,072	0,073	0,066	0,073					
SAB20	0,137	0,087							
DAB8	0,083	0,083							
DAB11	0,002	0,002	0,002	0,002					
DAB12									
X14-1									
X14-2		0,695	0,772	0,768	0,776				
X14-5	1,226								
X14-6	0,355	0,355	0,315						
X14-13	0,942	0,942							
X14-14	0,922								
X14-15	0,867	0,907	0,920						
Omlänk	1,796								
SP2		1,030		0,944	0,851				
SP4	0,727								
SP5	0,322	0,349	0,358	0,363					
SP7	1,075	1,183	1,147	1,183					
SP8	1,221	1,221	1,221	1,191					
SP9	1,635	1,635							
SP10	1,621								
SP11	1,630								
DCU3	0,718	0,711	0,651	0,711	0,660	0,620			
Slangpaket									

Table 3-8: Summary of workload per production cell for the total demand and the production hall forklifts in the gear mismatch scenario.

	Total			Abhall			Chall		
	Min	Normal	Max	Min	Normal	Max	Min	Normal	Max
IC5	7,156	6,441	6,416	2,131	2,139	2,131			
IC6	2,575	2,832	5,150	1,069	1,176	2,137			
IC7	7,738	8,443	7,738	3,298	3,598	3,298			
IC8									
IC9	5,681	5,779	5,681	0,155	0,158	0,155			
IC10									
IC11									
IC12	2,784	3,738	2,784	0,128	0,120	0,089			
IC13	4,207	4,824	4,207	0,155	0,138	0,120			
IC14									
IC15	6,454	6,573	6,454	0,169	0,172	0,169			
IC16	6,712	7,106	8,233	0,234	0,248	0,287			
IC17									
SAB9									
SAB11	7,545	7,545	7,545	0,378	0,378	0,378			
SAB12									
SAB13	3,709	2,176	3,709	0,195	0,114				
SAB14	6,760	4,951	6,760	0,278	0,204	0,139			
SAB16	3,139	0,918	3,139	1,202	0,352	1,202			
SAB17	4,020	2,387	2,010	0,102	0,060	0,051			
SAB18	7,531	7,223	5,135	2,342	2,246	2,342			
SAB19	5,260	9,758	13,808	0,245	0,173	0,094			
SAB20									
PAB7	4,119	3,658	4,119	1,781	1,582	1,781			

	Total demand			Abhall			Chall		
	Min	Normal	Max	Min	Normal	Max	Min	Normal	Max
PAB8	14,600	14,960	16,847	5,263	4,673	5,263			
PAB9	9,928	7,208	9,928	3,043	4,248	5,852			
PAB10	4,019	9,304	10,048	4,006	3,710	4,006			
PAB11									
PAB12	12,161	10,198	12,161	3,828	4,494	5,359			
PAB13	7,215	6,336	4,723	3,184	2,796	3,184			
DAB8		2,520	5,727		1,437	3,266			
DAB11	6,883	6,912	5,163	2,670	2,682	2,670			
DAB12	7,373	5,805	7,373	1,983	2,515	3,194			
X14-1	1,991	1,991	1,991	0,087	0,087	0,087	0,679	0,679	0,679
X14-2	6,665	6,436	5,272	0,279	0,270	0,221	2,504	2,418	1,981
X14-5	2,159	1,199		0,003	0,002		0,930	0,517	
X14-6	1,100	0,430		0,032	0,013		0,713	0,279	
X14-13	3,485	2,864	1,742	0,072	0,059	0,036	1,529	1,257	0,765
X14-14	2,021	1,605		0,042	0,034		1,057	0,839	
X14-15	4,771	3,386	3,135	0,089	0,063	0,058	1,923	1,365	1,264
Omlänk		0,457	3,238		0,012	0,087		0,191	1,355
SP2	20,106	20,654	22,664	2,205	2,265	2,486	14,124	14,509	15,922
SP4		1,569	2,168		0,247	0,342	1,099	0,795	1,099
SP5	7,424	8,129	10,022	1,419	1,554	1,916	4,930	5,398	6,655
SP7	3,473	2,518	2,388	0,032	0,023	0,022			
SP8	4,560	3,952	3,040	0,213	0,277	0,319	0,578	0,501	0,385
SP9	3,537	6,933	7,075	0,670	1,314	1,341	1,232	2,415	2,465
SP10		6,609	7,184		0,327	0,356		4,791	5,207
SP11		3,477	3,745	0,015	0,014			1,950	2,100
DCU3	20,239	22,002	23,510	2,002	2,177	2,326	15,395	16,736	17,883
Slangpaket									
Total	229,101	241,806	262,031	44,998		56,764	46,694	54,640	57,759

Table 3-9: Summary of workload per production cell for the work cell forklifts USM1 and SM1P for the gear mismatch scenario.

	USM1			SM1P		
	Min	Normal	Max	Min	Normal	Max
IC5						
IC6						
IC7						
IC8						
IC9						
IC10						
IC11						
IC12						
IC13						
IC14						
IC15						
IC16				0,173	0,183	0,212
IC17						
SAB9						
SAB11				7,161	7,161	7,161
SAB12						
SAB13					2,060	3,512
SAB14				3,235	4,739	6,470
SAB16	0,006	0,002	0,006	1,788	0,523	1,788
SAB17				1,959	2,327	3,919
SAB18				4,897	4,697	4,897

	USM1			**SM1P**		
	Min	Normal	Max	Min	Normal	Max
SAB19				5,159	9,569	13,542
SAB20						
PAB7		2,076	2,338			
PAB8	10,038	10,285	11,582			
PAB9	4,076	2,959	4,076			
PAB10	2,416	5,594	6,041			
PAB11						
PAB12	4,857	5,702	6,800			
PAB13	4,032	3,541	4,032			
DAB8	2,295	1,010	2,295			
DAB11	4,205	4,222	4,205			
DAB12	4,179	3,290	4,179			
X14-1						
X14-2						
X14-5						
X14-6						
X14-13						
X14-14						
X14-15						
Omlänk						
SP2						
SP4						
SP5						
SP7						
SP8						
SP9						
SP10						
SP11						
DCU3						
Slangpaket						
Total	36,104	38,681	45,553	24,372	31,260	41,501

Table 3-10: Summary of workload per production cell for the work cell forklifts SM23 and SM4 in the gear mismatch scenario.

	SM23			SM4		
	Min	**Normal**	**Max**	**Min**	**Normal**	**Max**
IC5	4,285	4,302	4,285			
IC6	1,506	1,657	1,506			
IC7	5,920	4,845	4,440			
IC8						
IC9	5,526	5,621	5,526			
IC10						
IC11						
IC12	2,695	3,619	2,695			
IC13	4,087	4,686	4,087			
IC14						
IC15	6,285	6,402	8,979			
IC16	6,305	6,675	7,734			
IC17						
SAB9						
SAB11	0,005	0,005	0,005			
SAB12						
SAB13		0,001	0,002			
SAB14	0,005	0,008	0,011			

	SM23			**SM4**		
	Min	Normal	Max	Min	Normal	Max
SAB16					0,042	0,143
SAB17						
SAB18				0,199	0,280	0,292
SAB19	0,008	0,015	0,021			
SAB20						
PAB7		0,001	0,001			
PAB8	0,002	0,002	0,002			
PAB9						
PAB10	0,001	0,001	0,001			
PAB11						
PAB12	0,002	0,001	0,002			
PAB13						
DAB8					0,073	0,165
DAB11				0,006	0,008	0,008
DAB12						
X14-1				1,225	1,225	1,225
X14-2				3,881	3,748	3,070
X14-5					0,681	1,226
X14-6				0,355	0,139	
X14-13				1,883	1,548	0,942
X14-14				0,922	0,732	
X14-15				2,760	1,959	1,814
Omlänk					0,253	1,796
SP2				3,777	3,880	4,257
SP4				0,727	0,526	
SP5				1,451	1,177	1,075
SP7				2,366	2,495	3,441
SP8				2,442	3,175	3,664
SP9				1,635	3,204	3,269
SP10					1,491	1,621
SP11					1,513	1,630
DCU3				3,302	3,090	2,842
Slangpaket						
Total	36,631	37,839	39,296	26,930	31,237	32,480

APPENDIX IV

Appendix IV contains all data and results in relation to the rail management scenario. First, table 4-1 display the workload in minutes per hour for each production cell and forklift is displayed both for min, normal and max. Following are charts for each production AMG and the variance on the total transportation demand. Finally charts for each forklift operator are included.

Table 4-1: Summary of workload per production cell for the total demand and the production hall forklifts in the rail management scenario.

	Total			**Abhall**			**Chall**		
	Min	Normal	Max	Min	Normal	Max	Min	Normal	Max
IC5	7,156	6,441		2,377	2,139	2,377			
IC6		2,832	8,240		1,176	3,420			
IC7	10,317	8,443	5,158		3,598	4,397			
IC8	1,268					0,578			
IC9	2,743	5,779	6,954	0,190	0,158				
IC10	5,317		4,431	1,120		2,016			
IC11									
IC12	3,977	3,738	3,977	0,128	0,120				
IC13	5,423	4,824	4,207	0,155	0,138	0,043			
IC14			4,450			3,304			
IC15		6,573	9,219	0,241	0,172				
IC16		7,106	8,233	0,287	0,248	0,234			
IC17									
SAB9	5,299		5,299	0,184					
SAB11		7,545	7,545	0,378	0,378				
SAB12	3,279			1,542		1,542			
SAB13		2,176	3,709	0,195	0,114				
SAB14	6,760	4,951	6,760	0,278	0,204				
SAB16	5,812	0,918	5,812		0,352	2,225			
SAB17	6,031	2,387		0,153	0,060				
SAB18	7,531	7,223		2,342	2,246				
SAB19		9,758	13,808	0,245	0,173				
SAB20	2,767			0,136					
PAB7		3,658	8,239		1,582	3,563			
PAB8		14,960	16,847		4,673	5,263			
PAB9		7,208	9,928		4,248	5,852			
PAB10		9,304	13,665		3,710	5,449			
PAB11	5,710			2,376		1,398			
PAB12		10,198	12,161		4,494	5,359			
PAB13	7,215	6,336	7,215	3,184	2,796	3,184			
DAB8	5,727	2,520	5,727		1,437	3,266			
DAB11	6,883	6,912		2,670	2,682	2,670			
DAB12		5,805	7,373		2,515	3,194			
X14-1	1,991	1,991	1,991	0,087	0,087	0,087	0,679	0,679	0,679
X14-2	6,665	6,436		0,279	0,270	0,279	2,504	2,418	
X14-5	2,159	1,199	2,159	0,003	0,002		0,930	0,517	0,930
X14-6	2,935	0,430		0,086	0,013		1,903	0,279	1,903
X14-13	3,485	2,864	3,485	0,072	0,059	0,036	1,529	1,257	1,529
X14-14	2,021	1,605	2,021	0,042	0,034	0,042	1,057	0,839	1,057
X14-15	4,771	3,386	4,771	0,089	0,063		1,923	1,365	1,923
Omlänk	3,238	0,457	3,238	0,087	0,012	0,087	1,355	0,191	1,355
SP2		20,654	22,664		2,265	2,486	14,124	14,509	15,922
SP4	2,168	1,569	2,168	0,342	0,247	0,342		0,795	1,099
SP5	10,022	8,129	10,022	0,426	1,554	1,916	6,655	5,398	6,655

	Total demand			Abhall			Chall		
	Min	Normal	Max	Min	Normal	Max	Min	Normal	Max
SP7	4,776	2,518		0,044	0,023				
SP8	5,928	3,952	5,928	0,415	0,277	0,415	0,751	0,501	
SP9	7,075	6,933	7,075		1,314	1,341	2,465	2,415	2,465
SP10		6,609	7,184	0,356	0,327	0,356		4,791	5,207
SP11		3,477	3,745	0,015	0,014		2,100	1,950	2,100
DCU3		22,002	23,510	1,375	2,177	2,619		16,736	20,138
Slangpaket									
Total	156,446	241,806	278,919	21,898	48,150	69,338	37,976	54,640	62,962

Table 4-2: Summary of workload per production cell for the work cell forklifts USM1 and SM1P in the rail management scenario.

	USM1			SM1P		
	Min	Normal	Max	Min	Normal	Max
IC5						
IC6						
IC7						
IC8						
IC9						
IC10						
IC11						
IC12						
IC13						
IC14						
IC15						
IC16					0,183	0,212
IC17						
SAB9						3,641
SAB11					7,161	7,161
SAB12				0,623		0,623
SAB13					2,060	3,512
SAB14					4,739	6,470
SAB16	0,011	0,002	0,011		0,523	3,310
SAB17					2,327	5,878
SAB18					4,697	4,897
SAB19					9,569	13,542
SAB20						2,457
PAB7		2,076	4,675			
PAB8		10,285	11,582			
PAB9		2,959	4,076			
PAB10		5,594	8,215			
PAB11			3,334			
PAB12		5,702	6,800			
PAB13	4,032	3,541	4,032			
DAB8	2,295	1,010	2,295			
DAB11	4,205	4,222	4,205			
DAB12		3,290	4,179			
X14-1						
X14-2						
X14-5						
X14-6						
X14-13						
X14-14						
X14-15						
Omlänk						
SP2						

	USM1			**SM1P**		
	Min	Normal	Max	Min	Normal	Max
SP4						
SP5						
SP7						
SP8						
SP9						
SP10						
SP11						
DCU3						
Slangpaket						
Total	10,543	38,681	53,404	0,623	31,260	51,703

Table 4-3: Summary of workload per production cell for the work cell forklifts SM23 and SM4 in the rail management scenario.

	SM23			SM4		
	Min	Normal	Max	Min	Normal	Max
IC5	4,780	4,302				
IC6		1,657	4,820			
IC7	5,920	4,845	2,960			
IC8	0,689					
IC9		5,621	6,764			
IC10	3,301		3,301			
IC11						
IC12	3,849	3,619	3,849			
IC13	5,267	4,686	5,267			
IC14	1,146					
IC15		6,402	8,979			
IC16		6,675	7,734			
IC17						
SAB9			1,474			
SAB11		0,005	0,005			
SAB12			1,114			
SAB13		0,001	0,002			
SAB14		0,008	0,011			
SAB16					0,042	0,265
SAB17						
SAB18					0,280	0,292
SAB19		0,015	0,021			
SAB20						0,174
PAB7	0,001	0,001	0,001			
PAB8	0,002	0,002	0,002			
PAB9						
PAB10	0,001	0,001				
PAB11						
PAB12		0,001	0,002			
PAB13						
DAB8					0,073	0,165
DAB11					0,008	0,008
DAB12						
X14-1				1,225	1,225	1,225
X14-2				3,881	3,748	3,881
X14-5					0,681	1,226
X14-6				0,946	0,139	
X14-13				1,883	1,548	1,883
X14-14				0,922	0,732	0,922
X14-15				2,760	1,959	2,760

	SM23			SM4		
	Min	Normal	Max	Min	Normal	Max
Omlänk					0,253	1,796
SP2				4,257	3,880	4,257
SP4				0,727	0,526	0,727
SP5				1,451	1,177	
SP7				1,075	2,495	4,732
SP8					3,175	4,763
SP9					3,204	3,269
SP10					1,491	1,621
SP11					1,513	1,630
DCU3				3,718	3,090	
Slangpaket						
Total	24,957	37,839	46,308	22,846	31,237	35,596

APPENDIX V

In appendix V, all data and the results from the batch process scenario is displayed in table 5-1. The table contains information regarding, production cell, production no., and the workload.

Table 5-1: Illustration of the workload for the batch process for Buckle production cells and the product variants produced there.

Buckle product cells	Product no	Batched work/unit	Batched work/hour	Weighted work/hour
X14-2	605749914	0,000	0,000	0,000
X14-2	605749900	0,000	0,000	0,000
X14-2	607944100	0,001	0,894	0,170
X14-2	606106900	0,001	0,894	0,202
X14-2	606107200	0,001	0,894	0,481
X14-2	606106914	0,004	2,681	0,014
X14-5	605600314	0,003	0,249	0,017
X14-5	605600300	0,003	0,249	0,232
X14-6	603427100	0,003	0,182	0,182
X14-13	603258214	0,012	1,514	0,037
X14-13	603257914	0,012	1,514	0,038
X14-13	603258200	0,012	1,514	0,042
X14-13	603257900	0,012	1,514	0,042
X14-13	606139900	0,017	2,270	0,133
X14-13	601149200	0,009	1,135	0,067
X14-13	605418900	0,004	0,568	0,075
X14-13	605419000	0,004	0,568	0,079
X14-13	600888500	0,004	0,568	0,143
X14-13	606139700	0,009	1,135	0,288
X14-14	606109100	0,003	0,548	0,059
X14-14	606139500	0,003	0,548	0,241
X14-14	606139300	0,003	0,548	0,249
X14-15	607335500	0,013	1,660	0,024
X14-15	607335400	0,017	2,144	0,033
X14-15	606836100	0,017	2,144	0,034
X14-15	606836000	0,013	1,660	0,028
X14-15	604919400	0,007	0,830	0,123
X14-15	604919500	0,009	1,072	0,161
X14-15	606177800	0,007	0,830	0,264
X14-15	606177600	0,009	1,072	0,343

APPENDIX VI

In appendix VI all data from the low volume scenario is presented. First, table 6-1 displays the total transport demand and specific transport demand for each of the low volume product cells. Finally, a chart of the effect each product cell has for the total demand, as well as the affect for each forklift, is presented.

Table 6-1: Transportation demand in total as well as for each specific forklift in the low volume cell scenario.

	Total demand	Abhall	Chall	USM1	SM1P	SM23	SM4
IC8	5,317	2,016				3,301	
IC10	3,019	1,377				1,641	
IC11	0,811	0,501	0,044			0,261	0,004
IC14	4,132	3,068				1,064	
IC17	2,062	0,088				1,974	
SAB9	5,299	0,184			3,641	1,474	
SAB12	3,279	1,542			0,623	1,114	
SAB20	2,767	0,136			2,457		0,174
PAB11	5,710	2,376		3,334			
Slangpaket	8,330	1,090	6,295				0,946

Figure 6-1: Illustration of the total transportation demand when production on a low volume cell is initiated.

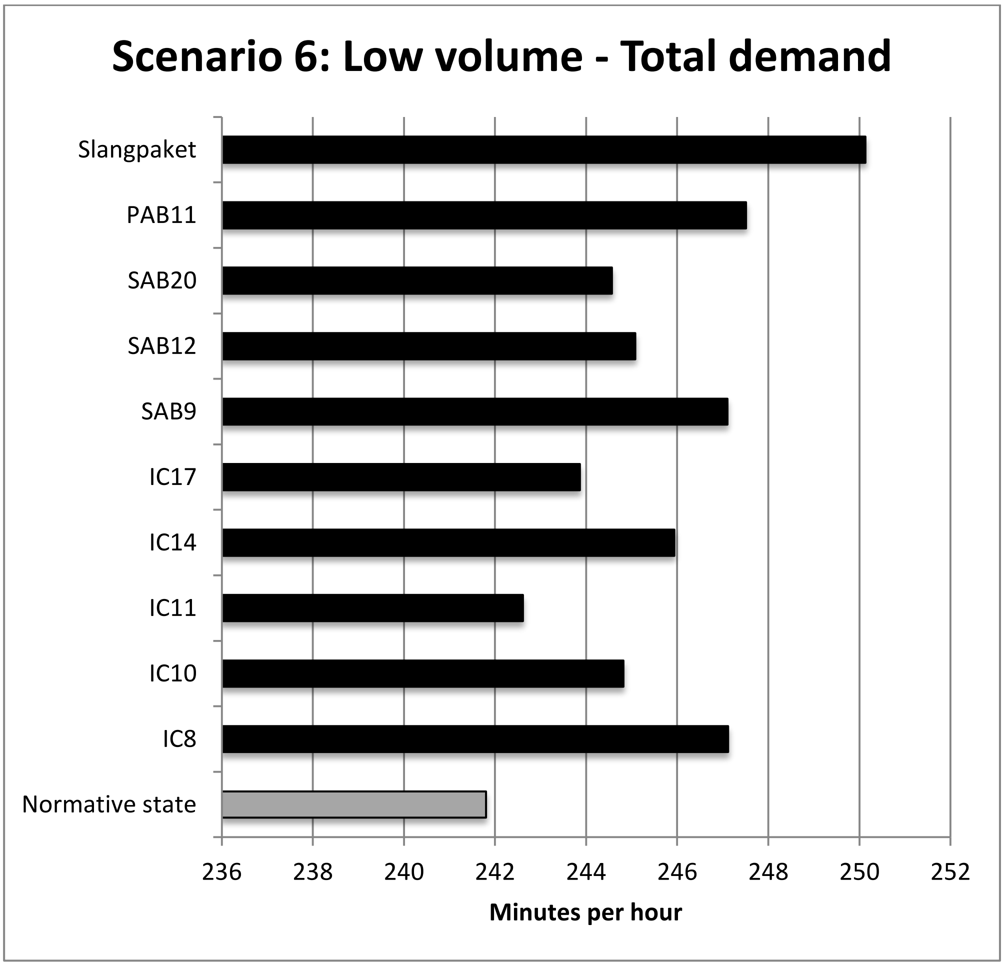


Figure 6-2: The transportation demand for the Abhall forklift when producing at a low volume cell in addition to the already modeled serial flow.

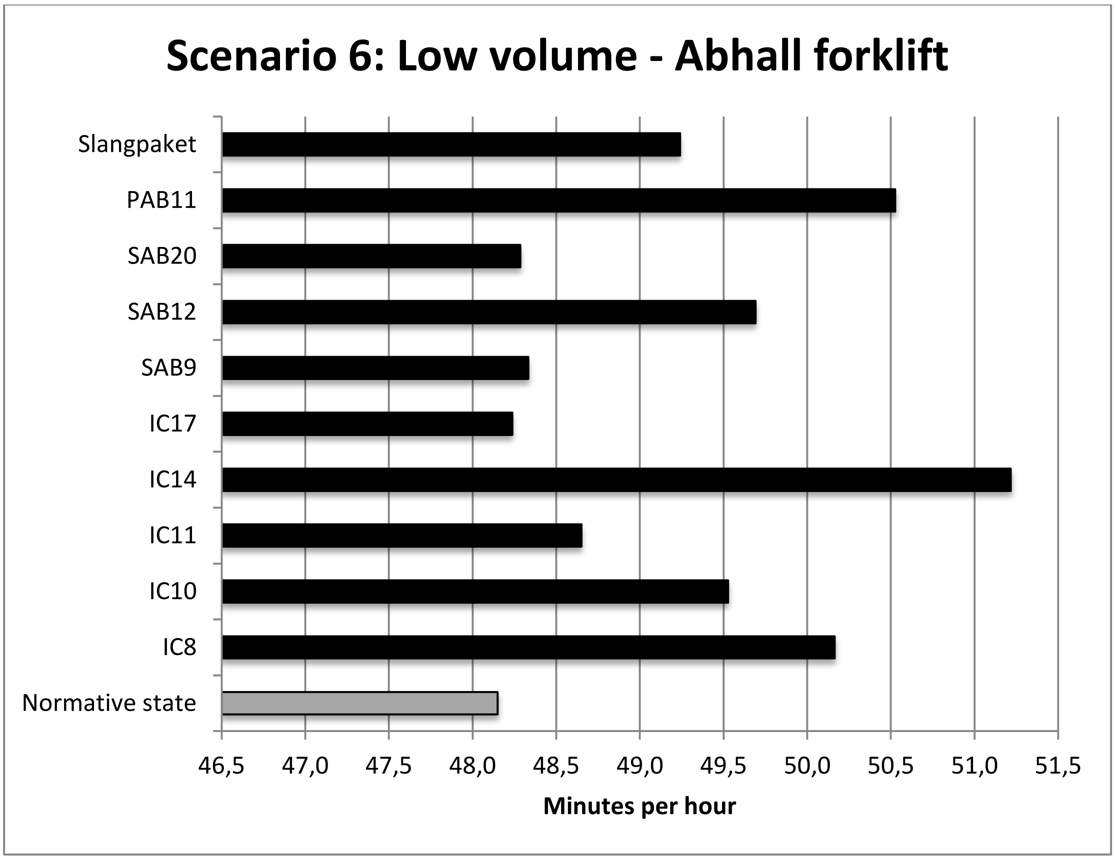


Figure 6-2: The transportation demand for the Chall forklift when producing at a low volume cell in addition to the already modeled serial flow.

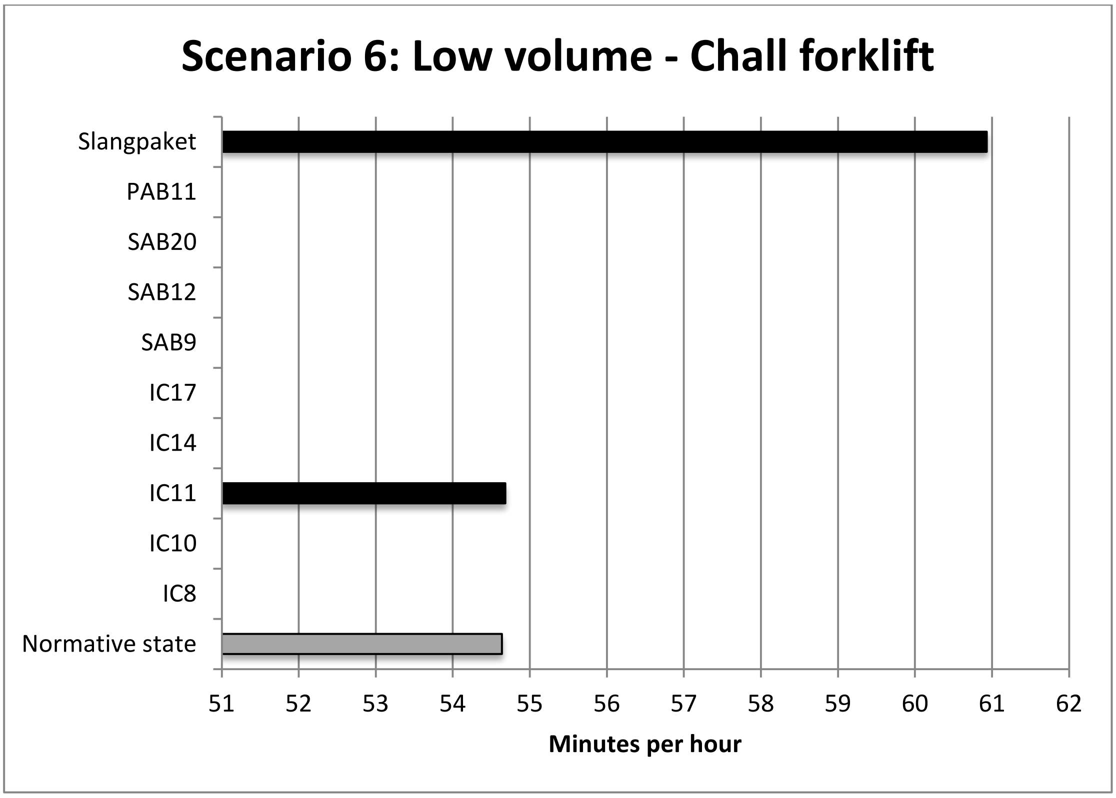


Figure 6-3: The transportation demand for the USM1 forklift when producing at a low volume cell in addition to the already modeled serial flow.

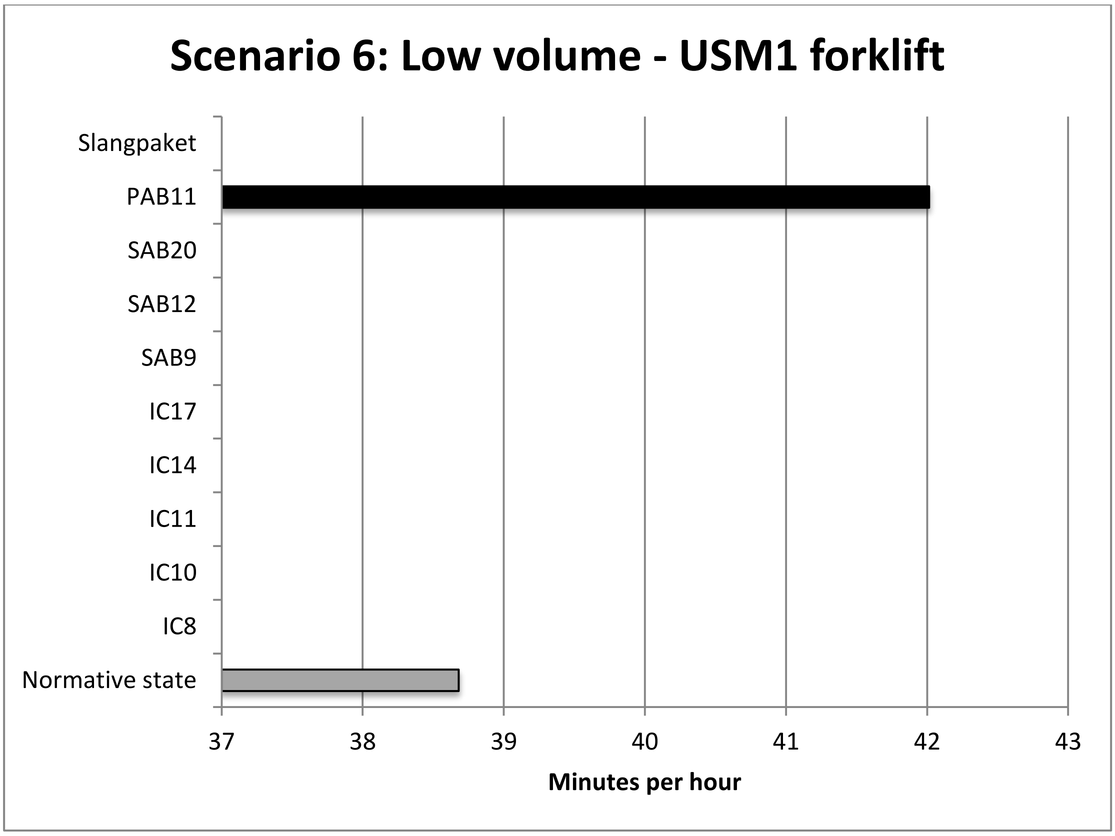


Figure 6-4: The transportation demand for the SM1P forklift when producing at a low volume cell in addition to the already modeled serial flow.

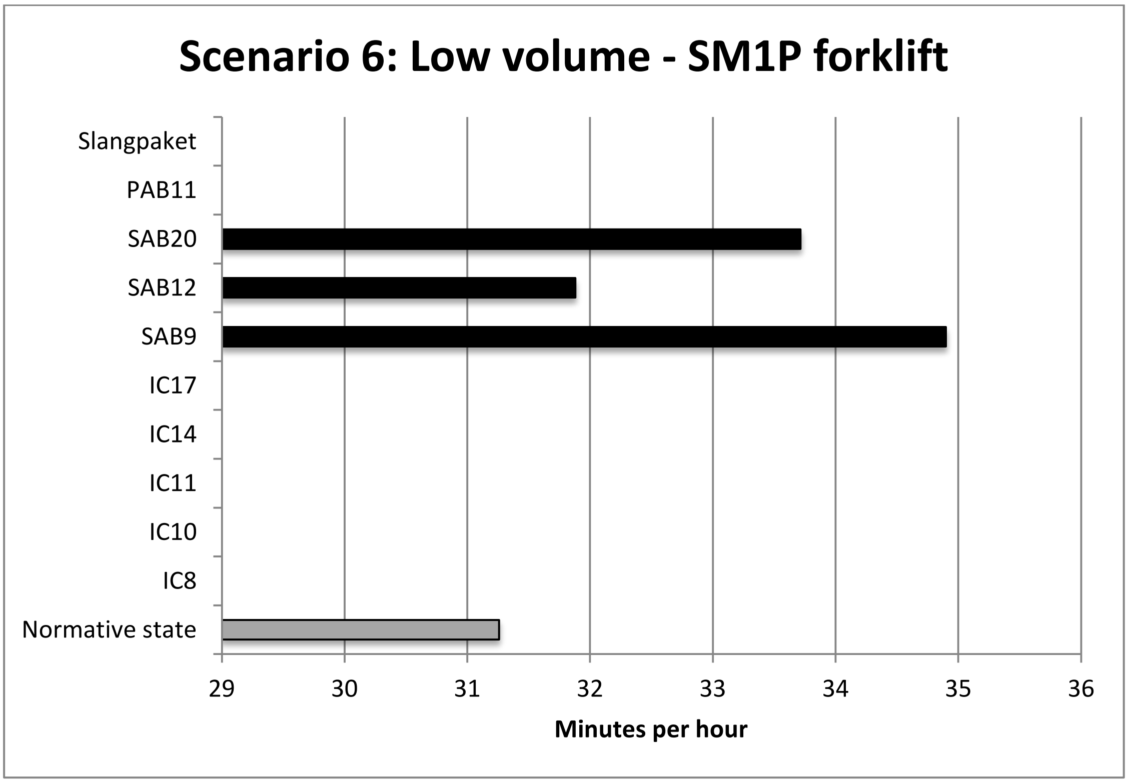


Figure 6-5: The transportation demand for the SM23 forklift when producing at a low volume cell in addition to the already modeled serial flow.

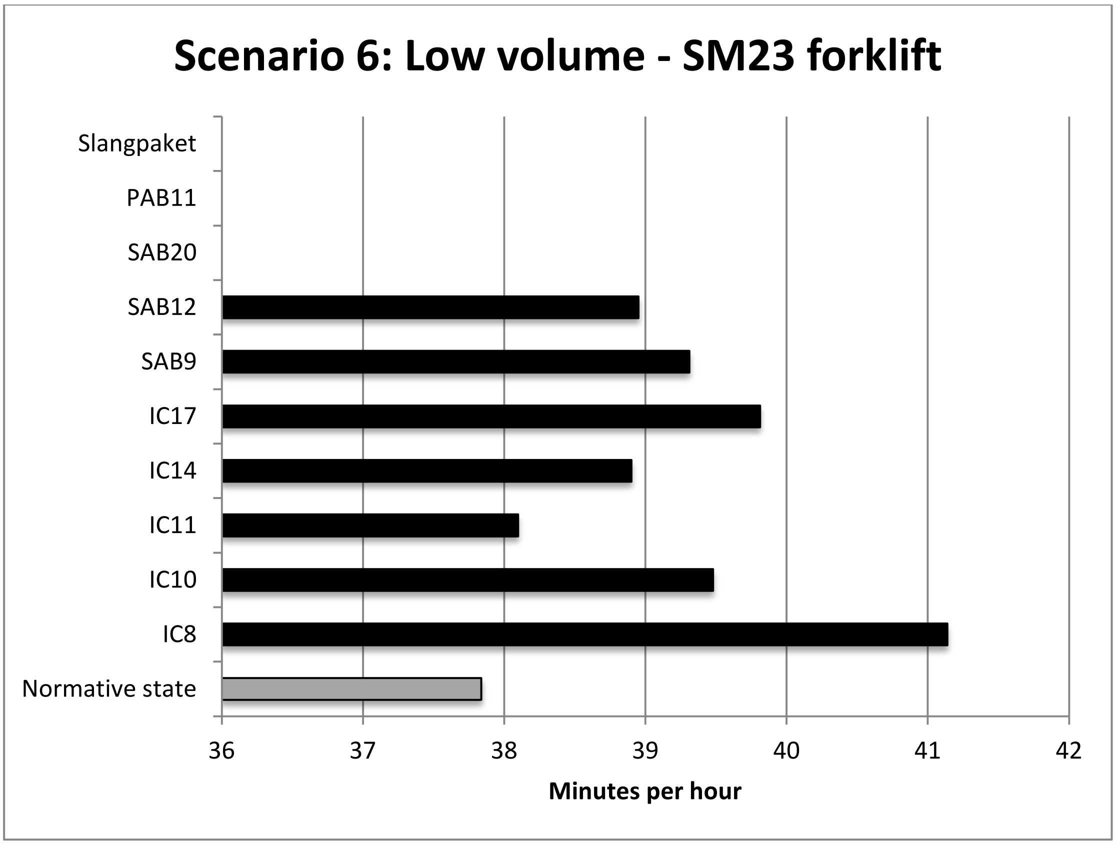


Figure 6-5: The transportation demand for the SM23 forklift when producing at a low volume cell in addition to the already modeled serial flow.

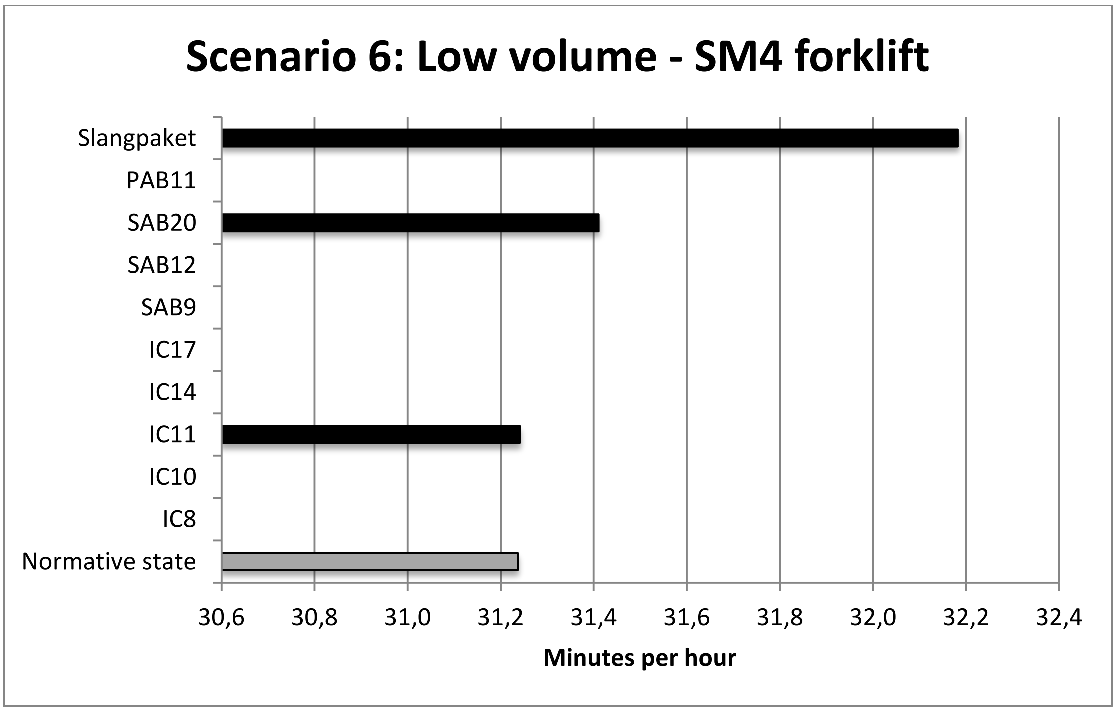
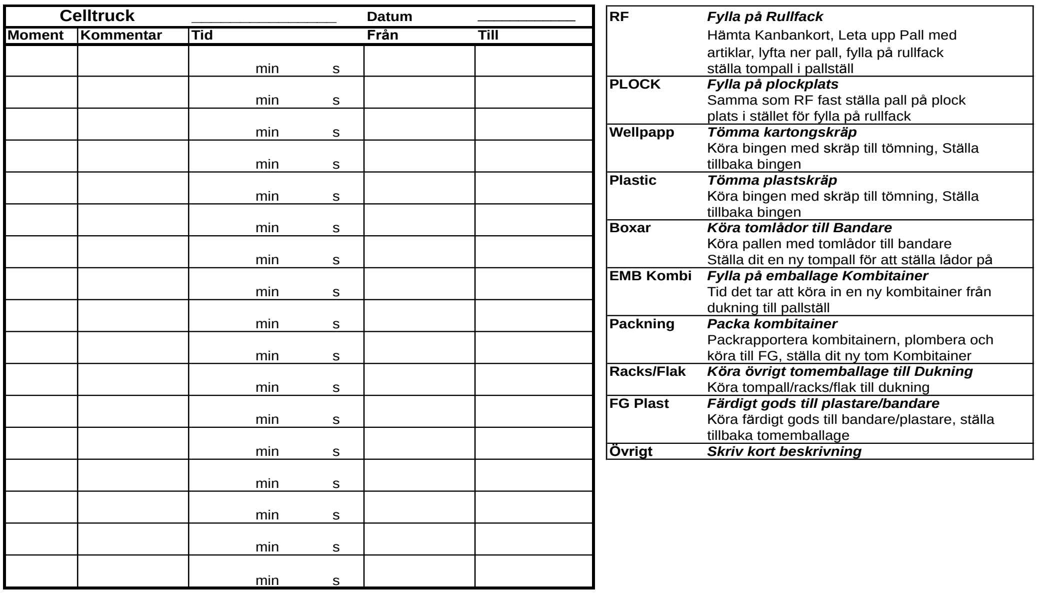


Figure 6-6: The transportation demand for the SM23 forklift when producing at a low volume cell in addition to the already modeled serial flow.

APPENDIX VII

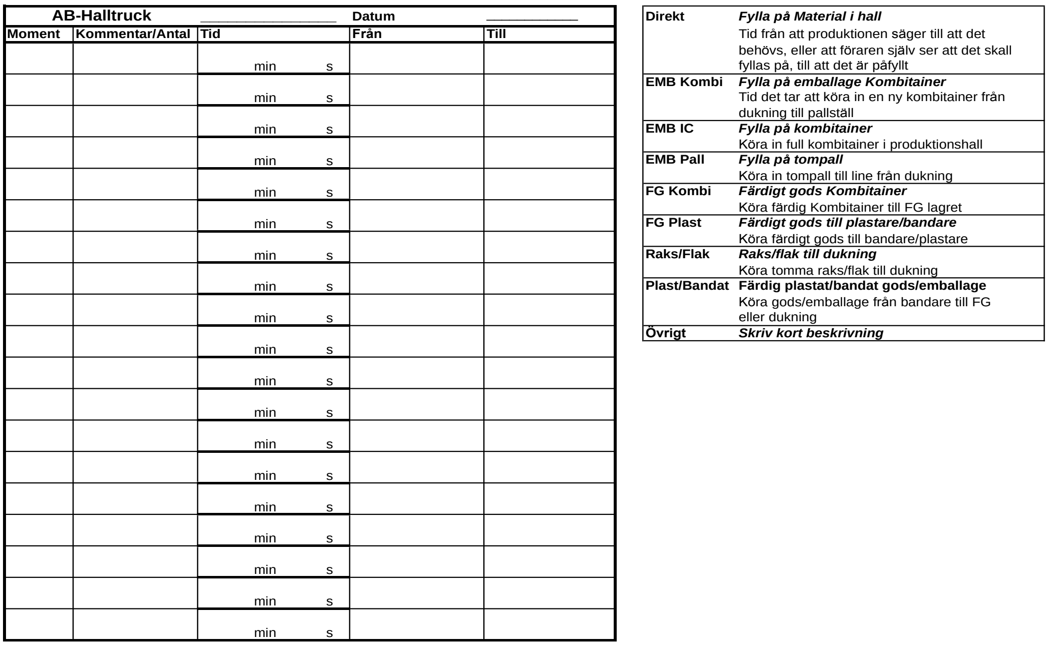
In Appendix VII, the templates created to perform the time study are included. Three different templates are used since the tasks are not always similar for Abhall, Chall and the cell forklifts.



Celltruck		_______________	Datum	___________
Moment	**Kommentar**	**Tid**	**Från**	**Till**
		min s		
		min s		
		min s		
		min s		
		min s		
		min s		
		min s		
		min s		
		min s		
		min s		
		min s		
		min s		
		min s		
		min s		
		min s		
		min s		
		min s		

RF	***Fylla på Rullfack*** Hämta Kanbankort, Leta upp Pall med artiklar, lyfta ner pall, fylla på rullfack ställa tompall i pallställ
PLOCK	***Fylla på plockplats*** Samma som RF fast ställa pall på plock plats i stället för fylla på rullfack
Wellpapp	***Tömma kartongskräp*** Köra bingen med skräp till tömning, Ställa tillbaka bingen
Plastic	***Tömma plastskräp*** Köra bingen med skräp till tömning, Ställa tillbaka bingen
Boxar	***Köra tomlådor till Bandare*** Köra pallen med tomlådor till bandare Ställa dit en ny tompall för att ställa lådor på
EMB Kombi	***Fylla på emballage Kombitainer*** Tid det tar att köra in en ny kombitainer från dukning till pallställ
Packning	***Packa kombitainer*** Packrapportera kombitainern, plombera och köra till FG, ställa dit ny tom Kombitainer
Racks/Flak	***Köra övrigt tomemballage till Dukning*** Köra tompall/racks/flak till dukning
FG Plast	***Färdigt gods till plastare/bandare*** Köra färdigt gods till bandare/plastare, ställa tillbaka tomemballage
Övrigt	***Skriv kort beskrivning***

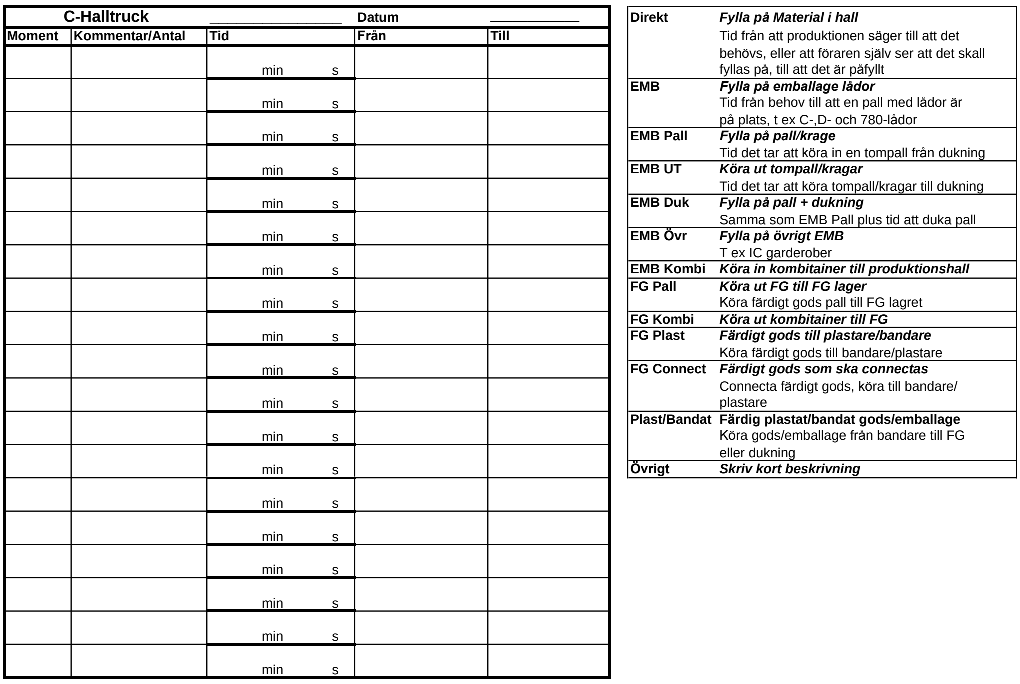
Figure 7-1: The template used for time study on work cell forklifts.



AB-Halltruck		_______________	Datum	___________
Moment	**Kommentar/Antal**	**Tid**	**Från**	**Till**
		min s		
		min s		
		min s		
		min s		
		min s		
		min s		
		min s		
		min s		
		min s		
		min s		
		min s		
		min s		
		min s		
		min s		
		min s		
		min s		
		min s		
		min s		
		min s		

Direkt	***Fylla på Material i hall*** Tid från att produktionen säger till att det behövs, eller att föraren själv ser att det skall fyllas på, till att det är påfyllt
EMB Kombi	***Fylla på emballage Kombitainer*** Tid det tar att köra in en ny kombitainer från dukning till pallställ
EMB IC	***Fylla på kombitainer*** Köra in full kombitainer i produktionshall
EMB Pall	***Fylla på tompall*** Köra in tompall till line från dukning
FG Kombi	***Färdigt gods Kombitainer*** Köra färdig Kombitainer till FG lagret
FG Plast	***Färdigt gods till plastare/bandare*** Köra färdigt gods till bandare/plastare
Raks/Flak	***Raks/flak till dukning*** Köra tomma raks/flak till dukning
Plast/Bandat	**Färdig plastat/bandat gods/emballage** Köra gods/emballage från bandare till FG eller dukning
Övrigt	***Skriv kort beskrivning***

Figure 7-2: The template used for time study on the Abhall forklift.



C-Halltruck __________________ **Datum** ____________

Moment	**Kommentar/Antal**	**Tid**	**Från**	**Till**
		min s		
		min s		
		min s		
		min s		
		min s		
		min s		
		min s		
		min s		
		min s		
		min s		
		min s		
		min s		
		min s		
		min s		
		min s		
		min s		
		min s		
		min s		
		min s		

Direkt	***Fylla på Material i hall*** Tid från att produktionen säger till att det behövs, eller att föraren själv ser att det skall fyllas på, till att det är påfyllt
EMB	***Fylla på emballage lådor*** Tid från behov till att en pall med lådor är på plats, t ex C-,D- och 780-lådor
EMB Pall	***Fylla på pall/krage*** Tid det tar att köra in en tompall från dukning
EMB UT	***Köra ut tompall/kragar*** Tid det tar att köra tompall/kragar till dukning
EMB Duk	***Fylla på pall + dukning*** Samma som EMB Pall plus tid att duka pall
EMB Övr	***Fylla på övrigt EMB*** T ex IC garderober
EMB Kombi	***Köra in kombitainer till produktionshall***
FG Pall	***Köra ut FG till FG lager*** Köra färdigt gods pall till FG lagret
FG Kombi	***Köra ut kombitainer till FG***
FG Plast	***Färdigt gods till plastare/bandare*** Köra färdigt gods till bandare/plastare
FG Connect	***Färdigt gods som ska connectas*** Connecta färdigt gods, köra till bandare/plastare
Plast/Bandat	**Färdig plastat/bandat gods/emballage** Köra gods/emballage från bandare till FG eller dukning
Övrigt	***Skriv kort beskrivning***

Figure 7-3: The template used for time study on the Chall forklift.