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Author:	O. Nyhuis

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Initiator (university):	Prof. dr. ir. G. Lodewijks
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Supervisor:	Dr. ir. H. P. M. Veeke
Date:	August 14, 2013

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Student:	O. Nyhuis	Assignment type:	Master thesis
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Subject: **Redesign Concept for Logistics of Volkswagen Commercial Vehicles in Hannover**

Context

Automobile manufacturers face strong competition among each other and have been coping with an increasingly difficult market in the last years. Volkswagen Commercial Vehicles, as one of the twelve brands of the Volkswagen Group, is no exception and has to increase profitability on all levels of the organization. Moreover, the group wants to become the world's leading manufacturer by the year 2018 with a production of 10 million vehicles annually and a return on sales of more than 8%. At the same time Volkswagen strives to become the best employer and reach the best customer satisfaction on the market. One of the ways of achieving the goals for 2018 is the Volkswagen Group production system, which includes just-in-sequence production (JISP). This concept seeks to set the production sequence at an early stage to harvest its potential on different levels, including the just-in-sequence (JIS) supply of components for the different vehicles.

The main plant of Volkswagen Commercial Vehicles in Hannover, Germany, currently produces roughly 24,000 Panamera bodies, 26,000 Amarok, and 135,000 T5 annually. This poses a large degree of complexity for the logistics department, which consequently creates a demand for efficient and effective communication structures and material flows.

Problem Definition

The extensive degree of complexity of the vehicle production becomes obvious when looking at the configuration variants of the T5 with a theoretical number of more than 1 trillion different configurations. This variance is a unique selling company for Volkswagen Commercial Vehicles, but the combination of this large variance and JIS supply processes require a very high performance with regard to just-in-sequence production. However, there are large degrees of scrambling of the

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sequence in the different sections of production, which result in the inability to predict the actual sequence in assembly adequately. Consequently, supply processes become less efficient and the potential of just-in-sequence production is harvested only partially.

Assignment

The assignment is to analyze the current process structures both internally and to external entities of the Volkswagen Commercial Vehicles plant in Hannover, Germany. Problems shall be identified and a concept to solve the identified problems shall be derived. This new concept has to take into account the key performance indicators for logistics at Volkswagen Commercial Vehicles (1) auxiliary procurement costs, (2) internally required area, (3) capital expenditures (CAPEX), (4) operational expenditures (OPEX), and (5) operative logistic times.

Execution

1. Formulate the main key performance indicators (KPI) of the organization
2. Analyze the current processes according to the Delft Systems Approach
3. Identify relevant areas for improvement and the corresponding problems
4. Formulate a definite problem definition
5. Define the boundary conditions for the solution
6. Develop a new structural model to improve the communication between the different entities and thus to improve the main KPI
7. Study relevant literature

The report should comply with the guidelines of the section. Details can be found on the website.

The professor,

Prof. dr. ir. G. Lodewijks

The TU supervisor,

Dr. ir. H. P. M. Veeke

Preface

I would like to thank the entire Volkswagen Commercial Vehicles department of logistics planning for the help and support during research and writing for this report; especially Dr. Dag Tegtmeyer and Thorsten Wilsdorf. I also appreciate the feedback I received from Dr. Hans P. M. Veeke and Prof. Dr. Gabriël Lodewijks of the Delft University of Technology and would like to express my appreciation for the time and sharing of knowledge of all the Volkswagen employees in sales, planning, supply, production, and distribution who contributed to my thesis.

Most importantly, I would like to dedicate this thesis to my family and thank them for their love and support, as I could not have done it without them.

Hannover, August 2013 Ole Nyhuis

Executive Summary

Since 1956 the Volkswagen Commercial Vehicles plant in Hannover produces Transporters. Over time the plant grew increasingly complex, and today roughly 13,000 employees produce 600 T5, 120 Amarok, and 40 Porsche Panamera bodies per day. It is the Volkswagen Group's declared goal to become the world's leading automotive manufacturer, which also sets goals for the brand of Volkswagen Commercial Vehicles.

This thesis focused on the order-to-delivery (OTD) process and its sub-processes of sales, planning, supply, production, and distribution. Its goal was to investigate the just-in-sequence production (JISP) concept and to provide a concept proposal to create more stable and robust logistics processes and to harvest the economic potential of JISP and just-in-sequence supply of components.

Within the OTD process there are a number of issues that were investigated using the Delft Systems Approach to find their causes. These issues are the large stocks of JIS components at the third level logistics provider (3PL), the large inventories of finished vehicles in distribution, and the rather low internal delivery reliability.

As root cause for the large stocks at the 3PL, the analysis identified the inaccurate information of JIS suppliers and a lack of knowledge of JIS suppliers about the supply process at Volkswagen. The large inventories in distribution are caused by a lack of information of the distribution department and the corresponding inability to plan. Moreover, the low internal delivery reliability is caused by process disturbances and negligence of differences in throughput times for certain characteristics of orders. These characteristics include non-standard roofs, double-layer paint, and painting of the vehicle on painting line 1. Together these root causes lead to the research question of how to improve the logistics processes and process communication without interfering with the current production process to improve efficiency and effectiveness in logistics.

For mitigation of the identified problems, three approaches were investigated: transfer of additional data and coaching for JIS suppliers, transfer of additional data for the distribution department, and the integration of scheduling and sequencing with sequence-shifting.

In the first proposal, JIS suppliers shall receive the planned assembly sequence rather than the body construction sequence. Moreover, coaching workshops shall be used to foster knowledge about the supply process and the information content of transferred data. Additionally, the workshops shall be used to optimize the component production scheduling and supply process per supplier to stabilize the logistics chain and create a greater security of supply. Experts from both suppliers and the logistics planning department of Volkswagen validated this proposal. Calculations were conducted to assess the solution for German JIS suppliers outside a 90km range of the plant. For these suppliers, the greater security of supply means the safety stocks van be reduced from three to somewhere between one and 1.6 days. This lead to a reduction of the total stock volume at the 3PL of 20% to 28%. Financially, it provides an annual surplus of €1,000 to €4,600, which does not include savings for less capital employed or the possibility to procure additional parts as JIS components.

The second proposal implies the transfer of sequence-related production data to the distribution department. This way the planning of vehicle shipping by truck is possible prior to vehicle completion, which reduces the average inventory times of vehicles. An expert of the distribution department validated this solution, and assessment shows a reduction of inventory by 22% for a reduction of the inventory time from 2.19 to 1.5 days. The annual savings are estimated at €13,700 for area reductions only and the investments required are expected around €12,900, yielding a payback period of approximately one year. Moreover, area reductions for distribution are imminent due to the construction of an additional pressing plant, which supports the decision to implement this proposal.

The third proposal comprises the integration of scheduling and sequencing to make rolling wave sequencing and thus sequence-shifting possible. This sequence-shifting denotes the practice of starting the body construction for vehicles with prolonged throughput times early to match the plan sequence in assembly. An expert of the program planning department validated the solution and assessment shows its positive impact on the delivery reliability. The delivery reliability in itself, however, neither reduces the costs directly, nor are positive effects on the other two proposals expected. Nevertheless, with the higher delivery reliability, the possible service level of the ASRS for assembly becomes significantly higher. In a situation without sequence restrictions, the service level increased from 85% to 95% for an ASRS with 289 dedicated resorting cells. Investments required for the implementation of scheduling and sequencing, however, are expected around €310,000, while the annual savings are expected to be a mere €8,000. Regardless, the significantly higher service level in assembly due to sequence-shifting provides a cornerstone for the future implementation of a long-distance JIS supply process.

Consequently, the final improvement concept includes the information and coaching of JIS suppliers, as well as the provision of additional data for distribution. In the current situation the implementation of sequence-shifting is not cost-effective. Moreover, the thesis also provides a rough overview of the steps necessary for implementation as a basis for a more elaborate implementation plan.

In conclusion, the possibility of sequence-shifting shall be kept in mind and investigation on possibilities for its implementation without the integration of scheduling and sequencing should be considered. Finally, the improvement concept proposal is beneficial for the efficiency and effectiveness of the OTD process and its implementation is therefore strongly recommended.

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List of Abbreviations

3PL	third level logistics service provider
AL	assembly line
ASRS	automatic storage and retrieval system
B2B	business-to-business
B2C	business-to-customer
BTO	build-to-order
BUS	business unit special vehicles
CAPEX	capital expenditures
CP	checkpoint
DELFOR	delivery forecast
DLP	double-layer paint
DSA	Delft Systems Approach
FIFO	first in, first out
FISFO	first in sequence, first out
IQR	interquartile range
JIS	just-in-sequence
JISP	just-in-sequence production
KPI	key performance indicator
KPS	Volkswagen Group production system, from German: *Konzern Produktions-System*
MB	mix bank
NLK	new logistics concept, from German: neues Logistikkonzept
NSR	non-standard roof
OPEX	operational expenditures
OTD	order-to-delivery
PL	painting line
PROPER	process-performance
SQ	sequence
SQD	sequence deviation, German: Sequenzabweichung
SQP	sequence performance, German: *Perlenkettengüte*
SWR	sequence window reliability, German: *Perlenkettenfenstertreue*
VIN	vehicle identification number

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1. Introduction

"1947. A chance encounter made an impact on automotive history. As the Dutch Importer Ben Pon walked across the grounds of the Volkswagen factory in April 1947, he came across a very strange vehicle. Some Volkswagen employees had built it themselves to make their work easier when transporting heavy parts from production hall to production hall. A little later, on April 23rd, this impression crystallized into an idea. Ben Pon took his notebook and sketched a type of vehicle that did not exist in the world at that time – a forward control vehicle with rear engine and a box shaped body." On March 8th, 1950, the first production vehicle according to Pon's sketch (Figure 1) left the plant in Wolfsburg, Germany. Four years and 100,000 T1 Transporters later the capacity of the Volkswagen factory in Wolfsburg did not meet the demand for production anymore. The company decided to build a factory for the Transporter only, and the foundation stone was laid in the beginning of 1955 in Hannover, Germany [1].

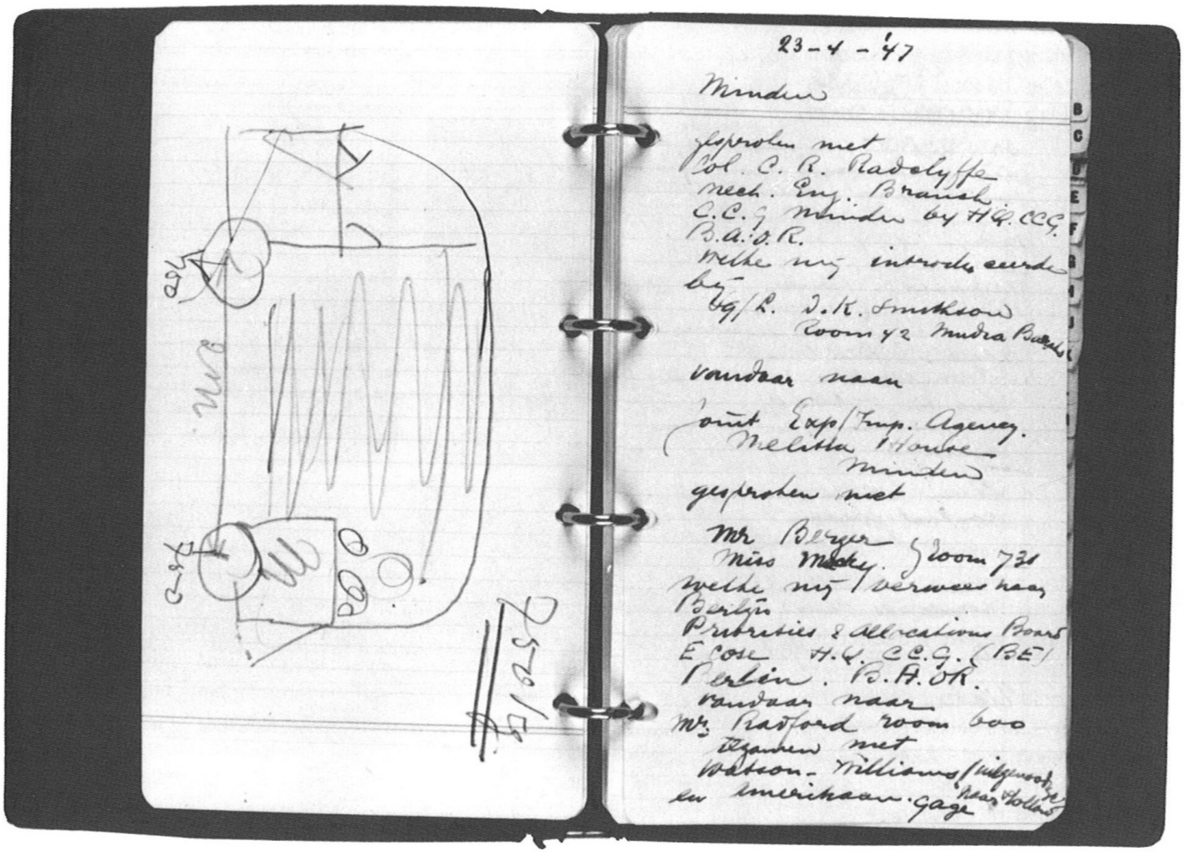

Figure 1: Ben Pon's notebook with the first sketch of the original Transporter[1]

[1] illustration from Wikipedia [70]

Since the first vehicle left production in Hannover in March 1956 a lot has changed. The currently produced Transporter is the T5 (see Figure 2), which will soon be revised for the second time, and the total number of T5 produced in Hannover until the end of 2012 is approximately 8.5 million. Moreover, since 2009 the plant in Hannover also produces the body for the Porsche Panamera and started production of the Volkswagen Amarok pickup truck in the middle of 2012 [2].

Figure 2: The 1956 T1 and the 2003 T5 Multivan[2]

The total production numbers of roughly 3,600 vehicles per week make for great complexity in terms of material and information flows [3]. Part of the resulting challenge is to ensure efficient and effective processes, of which this report tackles the order-to-delivery (OTD) process[3] and its sub-processes.

1.1. Goals and Scope of the Thesis

The goal of this thesis is to analyze and evaluate the influences of the order sequence with regard to the processes of the Volkswagen Commercial Vehicles production facility in Hannover, Germany, from a logistics point of view. This includes the OTD process and the sub-processes of sales, planning, supply, production, and distribution (see section 2.4). Influencing variables and material and information flows are to be determined to identify and define problems with regard to logistics and subsequently to derive concepts for improvement. These concepts should create more stable and robust logistic processes in the production of vehicles and to harvest the economic potential of a high adherence to the planned sequence. The final concept of this thesis should include a definition of the required quality of both information flows and call-off orders for optimal supply of parts and components for production and assembly, as well as an analysis of the concept.

[2] illustration from Volkswagen AG [1]
[3] in German: Kundenauftragsprozess

1.2. Structure of the Report

The structure of this thesis is illustrated in Figure 3. After the introduction in chapter 1, the thesis will commence with the setting of the thesis and the surrounding conditions in chapter 2. The company's objectives of different levels of the organization are presented and in section 2.4 the current processes of order-to-delivery, sales, planning, production, logistic supply, and distribution of vehicles with regard to the flows of information and material are described. Subsequently, the production scheduling concept of just-in-sequence production is introduced in section 2.5.

Figure 3: Structure of the report

In chapter 3 the Delft Systems Approach is introduced briefly and used for process analysis of the current processes of the Volkswagen Commercial Vehicles plant in Hannover (see Figure 4), which includes the identification of influencing factors. These influencing factors and the process analysis provide a scaffold for the definition of problems in the process in chapter 4. Following this analysis of the current processes, a concept for the improvement of communication processes and information flows is introduced and discussed in chapter 5. This discussion provides the basis for an improvement concept proposal in chapter 6. Chapter 7 provides rough outline of what is required for implementation of the concept, before the report will be concluded in with a conclusion and recommendations for the improvement of the logistics processes of the company.

Figure 4: The Volkswagen Commercial Vehicles plant in Hannover

2. Setting of the Thesis

This research is conducted in the Hannover plant of Volkswagen Commercial Vehicles, a brand of the Volkswagen Group. In total the Volkswagen Group consists of twelve automotive brands as depicted in Figure 5: Volkswagen, Audi, SEAT, ŠKODA, Porsche, Bentley, Bugatti, Ducati, Lamborghini, Volkswagen Commercial Vehicles, Scania and MAN. In total, the Volkswagen Group[4] delivered 9.07 million vehicles in 2012 [4], with approximately 550.000 employees globally and 250.000 employees in Germany alone. By numbers of employees only, the Volkswagen Group grew by about 70% since 2007 [5].

Figure 5: Automotive brands of the Volkswagen Group[5]

2.1. Volkswagen Commercial Vehicles

Volkswagen Commercial Vehicles produces four different models of cars in Europe: T5, Amarok, Caddy, and Crafter. These models are shown in Figure 6. Of the four models, only the T5 variants Transporter and Multivan, and the Amarok pickup truck are built in the plant in Hannover. In addition to these Volkswagen Commercial Vehicles models, however, the Porsche Panamera car body is built and painted in Hannover as well, and subsequently shipped to Leipzig by train for further assembly. In the remainder of the thesis, the Panamera production will only be considered in case of interference with the Amarok or T5 production.

Figure 6: Four products of Volkswagen Commercial Vehicles: Amarok, Crafter, Caddy, and T5[6]

[4] excluding MAN and Scania
[5] illustration based on Volkswagen AG [60]

The business areas of Volkswagen Commercial Vehicles are both business-to-business (B2B) and business-to-customer (B2C), as especially Caddy and T5 come in several commercial and passenger car models. The total number of vehicles sold in 2012 was 550,400, while a total of 160,300 T5 were sold in the same period [6].

For the plant in Hannover with its roughly 13,000 employees, the difference in customers results in large variance in the configuration of vehicles and consequently the work effort for the production. Theoretically, the T5 has roughly 3,000 body variants and in total more than 1 trillion different configurations; from an entry-level Transporter delivery van to a highly equipped passenger car Multivan Business [7].

Much lower in complexity, but still substantial – with approximately 340 body alternatives – is the Porsche Panamera car body that is built and painted in Hannover and then shipped to Leipzig by train for further assembly [8]. The Amarok has the least degree of complexity, with just 16 body variants [9].

Despite the number of different models and configurations the production is organized as line production. In order to keep the required stock of semi-finished goods to a reasonable level, a great deal of communication and control of the supply processes is required. For the pursuit of the Volkswagen Group's strategy it is important that the communication also includes the roughly 970 suppliers of parts, components, and modules, both just-in-sequence (JIS) and otherwise.

2.2. Strategy of the Volkswagen Group

The *Strategy 2018* of the Volkswagen Group dictates the goals for the year 2018: "positioning the Volkswagen Group as a global economic and environmental leader among automobile manufacturers" with the sub-goals of becoming a world leader in customer satisfaction and quality, increasing annual sales to 10 million vehicles by 2018, increasing the return on sales before tax to at least 8%, and to become the top employer across all brands, companies, and regions [10]. Figure 7 summarizes these goals graphically.

Figure 7: Goals for the Strategy 2018[7]

[6] illustration from Volkswagen Nutzfahrzeuge [55]
[7] illustration based on Volkswagen AG [42]

Part of this strategy is the Volkswagen Group's production system (KPS)[8], which strives to make the Volkswagen Group a value creation-focused, synchronous company through four main principles of tact, flow, pull, and perfection. In the course of this production system, a new logistics concept (NLK) was developed and is currently being implemented step by step within the Volkswagen Group. In the NLK there are six of fields of action, which treat the following aspects:

1. order system and balanced production
2. in-house logistics
3. inbound logistics
4. organization of suppliers
5. qualification of employees
6. distribution of vehicles

A detailed description of both KPS and NLK can be found in Appendix B. Meanwhile, the strategic goals are unsuitable for day-to-day operations. Therefore operational goals are set for every year and will be discussed in the following section.

2.3. Goals of the Organization

The goals within the strategy of Volkswagen Group eventually translate to operational goals applicable for all brands and plants. One of Volkswagen's main processes is the order-to-delivery process, which will be described in more detail in section 2.4.1. This OTD process has the main goals of (external) **delivery reliability**, delivery period (or **throughput times**), ability to deliver (internal **delivery reliability**), and **change flexibility**.

Additionally, the operational goals and corresponding target values 2013 for the logistics department of Volkswagen Commercial Vehicles in Hannover are listed in Table 1 and provide a second set of assessment criteria for this thesis. The specific goals will be treated in more detail in the corresponding sections of this report.

Table 1: Operational goals of logistics 2013 for Volkswagen Commercial Vehicles in Hannover

ID	key figure	target
1	sequence window reliability at the beginning of body construction (R150)	**99.8%**
2	adherence to the day schedule at the beginning of assembly (M100) for the T5	**≥ 80% 1st half of 2013** **≥ 90% 2nd half of 2013**
3	production skew	**≤ 1 week** **≤ 200 vehicles**
4	vehicle throughput times from the beginning of body construction to completion	**4.7 days (T5)** **5.0 days (Amarok)**
5	externally leased area	**≤ 2,900 m^2**
6	costs of logistics per vehicle	**€1,639**

[8] from German: Konzern-Produktionssystem

Grouping of these goals makes it easier to keep track. The sequence window reliability, the adherence to the day schedule, and the production skew all aim at high **delivery reliability**. While the first two key figures treat the internal delivery reliability, the third aims mostly at external delivery reliability, that is, towards the customer. Key figures four through six will be considered under the more generic terms of **throughput times**, **area requirement**, and **auxiliary procurement costs**, respectively.

Moreover, in the logistics planning department the most common key performance indicators (KPI) for projects are **operational expenditures (OPEX)**, **capital expenditures (CAPEX)**, **operative times** for logistics, **area requirements**, and **auxiliary procurement costs**. These project KPI are used as a third set of assessment criteria.

When combining the three sets of goals some of the individual goals are conjunct. The remaining eight groups of goals are summarized in spider charts to quickly overview assessment of solutions with regard to above goals. One such chart is illustrated in Figure 8 and will be used in the assessment of measures for improvement in chapter 5 of this report. The darker line that connects the center of each spoke resembles the current situation, which acts as a reference for assessment. The further away from the center a measure is, the better is its performance with regard to the specific key figure.

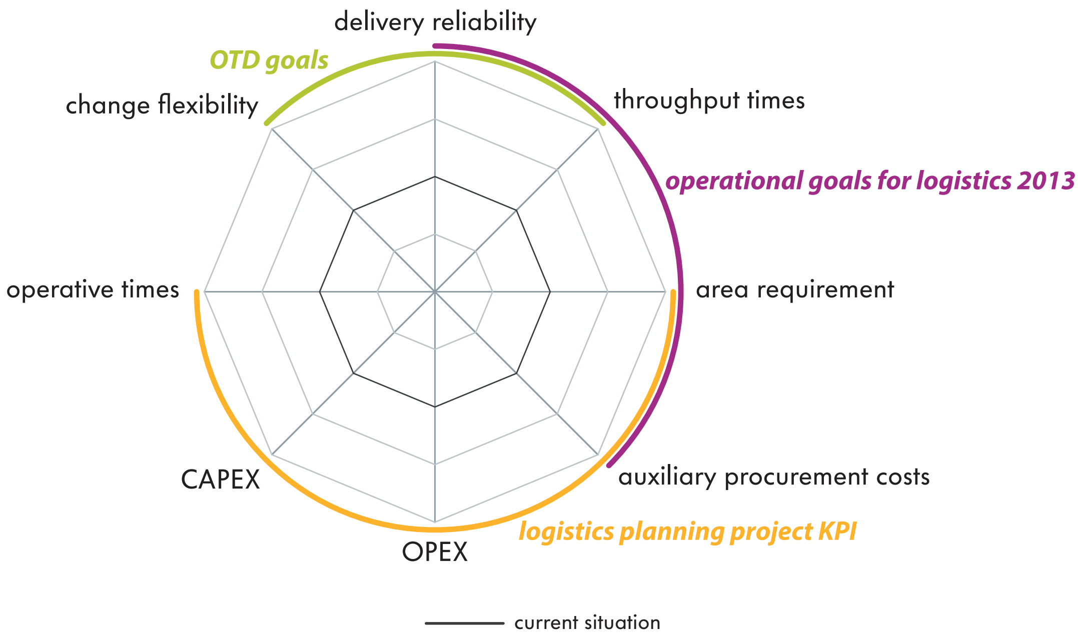

Figure 8: Spider chart used for assessment with regard to the organization's goals

In the following section the OTD process as one of the core processes of Volkswagen is described. Additionally, its sub-processes are also described in detail to provide a basis for process analysis in chapter 3.

2.4. Description of the Organization's Processes

The Volkswagen Group has three core processes as shown in Figure 9: the product process, the OTD process, and the customer service process. While the product process seeks to create mature products that are worth entering the market through development over the entire life-cycle, the order-to-delivery process handles customer orders, the production of vehicles, and the handover of vehicles. Lastly, the customer service process covers the entire life-cycle of the car and handles lifetime services provided to the customer [11].

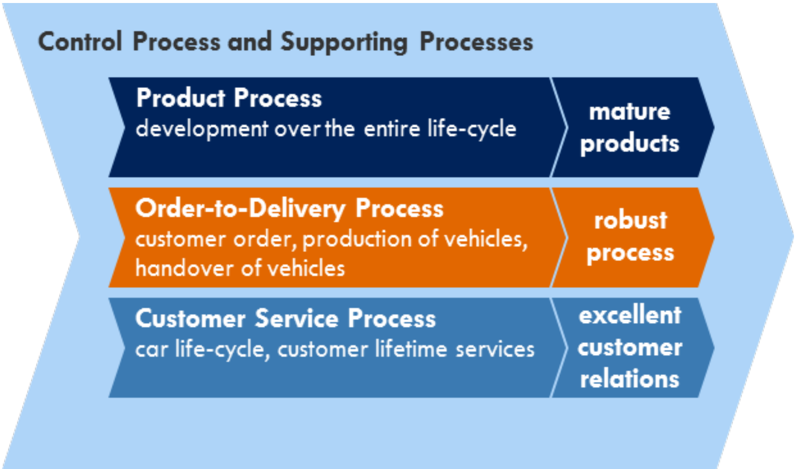

Figure 9: Core processes of the Volkswagen Group[9]

For this research, however, only the OTD process and its sub-processes are relevant and will be described in more detail in the following chapters.

2.4.1. Order-to-Delivery Process

Essentially, the OTD process covers everything from the dealer ordering a car as the customer of Volkswagen to the delivery of the vehicle to the dealer. When examining it in more detail, the OTD process contains five sub-process areas. Figure 10 illustrates the processes schematically.

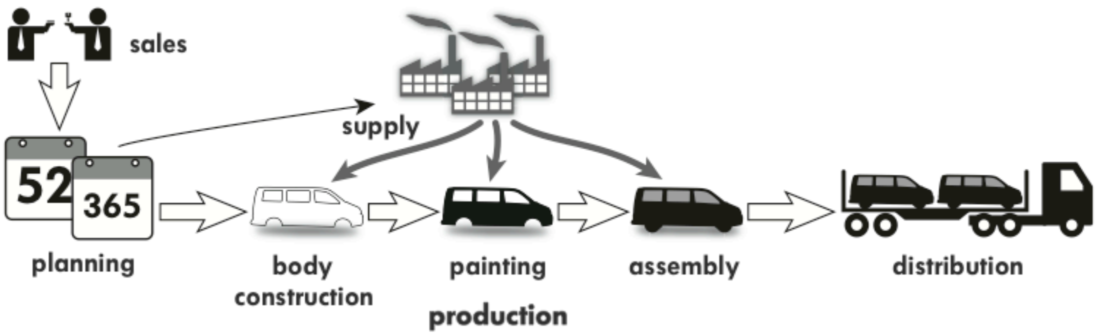

Figure 10: The order-to-delivery process' sub-process areas

The OTD process covers sales, the planning of orders and the supply of material from suppliers to production, with the three main production processes of body construction, painting, and assembly. Lastly, the distribution process ensures the orders are delivered to the customer.

[9] illustration based on AutoUni Volkswagen AG [11]

As mentioned, the OTD process starts with the importers' or dealers' customer orders, as production is based for 100% on built-to-order[10]. In some cases, however, the customer is not an importer or dealer but the sales division of the brand. The difference between consumer orders and contractually agreed turnover quantities is filled up with orders for the dealers' or importers' stocks. These turnover quantities are based on sales forecasts and remaining capacities that result from contractually set minimum buy-off quantities from suppliers on the one hand, and the inflexibility of shift work in the Volkswagen production sites on the other. Note that this built-to-order (BTO) rate of 100% is different from the German automobile industry average of BTO production of roughly 65% [12].

As mentioned earlier, the general goals set by Volkswagen for the OTD process with regard to the customer satisfaction are delivery reliability, lead time, ability to deliver, and change flexibility. The strategic goal of best customer satisfaction, as set in the strategy 2018 (see section 2.2), can be achieved through these sub-goals. The goal for delivery reliability is the commitment to delivery in a specific week at ordering and a specific day two weeks before delivery. Additionally, lead times for customer-specific orders shall not exceed a critical value. Object for the ability to deliver is that the scheduling of orders within a planned delivery period is reliable. Moreover, the change flexibility goal seeks to provide a high flexibility for the customer to change the order even after ordering at the dealer. These goals are summarized in Figure 11.

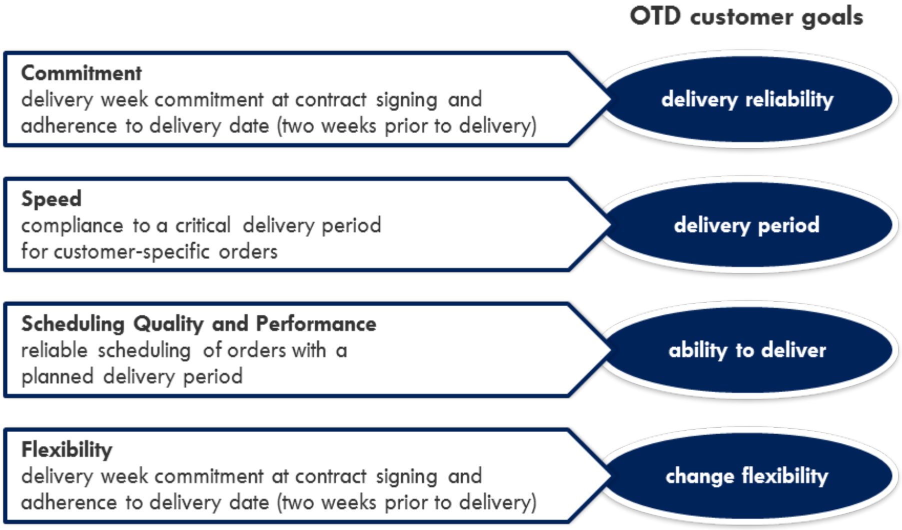

Figure 11: Goals for the order-to-delivery process[11]

As mentioned, within the OTD process includes the sales process, the planning process, the supply process, the production process, and the distribution process. An illustration of the OTD process in Appendix C shows the parallel nature of the processes, which will be covered in the following sections.

[10] i.e., production quantities are purely customer-specific orders
[11] illustration based on AutoUni Volkswagen AG [58]

2.4.2. Sales Process

Within the course of the sales process, the dealers' customer orders are transferred to Volkswagen and preliminarily planned in a specific week using level indicator setpoints for different features, such as air-conditioning, diesel engines, paint type and transmission. This step is explained in more detail in the following section. If the contractually agreed sales quantities per dealer – or importer for international customers – are not met, the sales department requests additional orders from the respective entities [13]. Subsequently the customer orders are scheduled as described in the following.

2.4.3. Planning Process

The planning process can also be described as a scheduling and sequencing process. In a first step the customer orders generated through sales are collected in a system called IFA[12], which uses level indicators to match customer orders with a specific, usually the first calendar week with available capacity for all vehicle characteristics. Note that capacities for characteristics may be restricted to contractual agreements with suppliers.

The final week schedule per week is created approximately four weeks and nine weeks before the planned vehicle completion for the T5 and Amarok, respectively. This step results in a week schedule for the completion checkpoint (CP) ZP8 and can be seen in Figure 12.

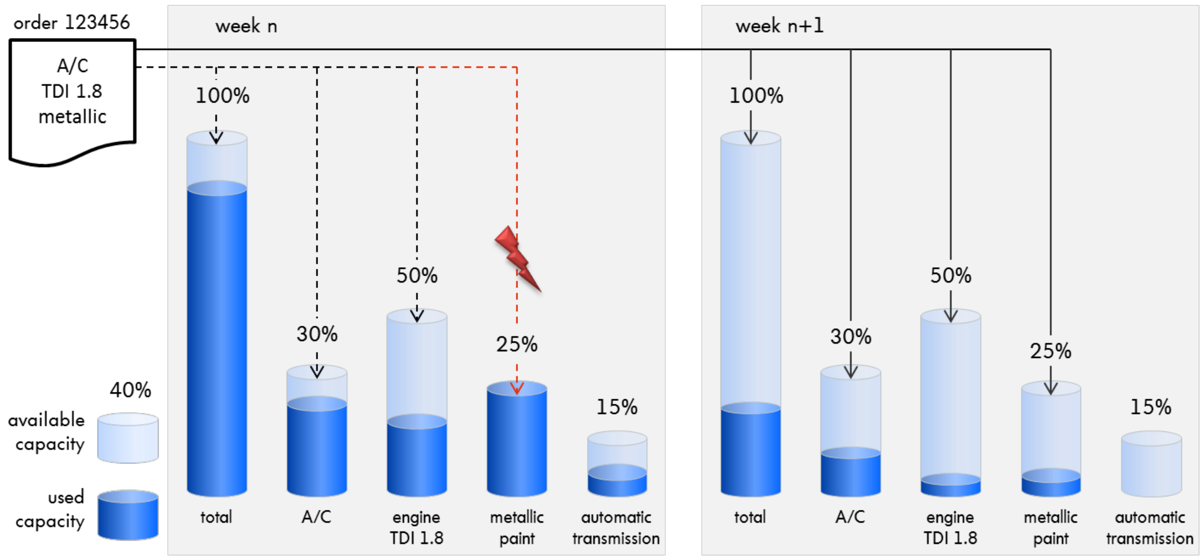

Figure 12: Fictional example of the use of level indicators for week capacity constraints[13]

In the example an order for a T5 Transporter with a diesel engine, air conditioning, and metallic paint is supposed to be scheduled to a production week. Due to the filled metallic paint level indicator the entire order is shifted to the following week, which has enough spare capacities for all vehicle characteristics.

[12] from German: Integrierte Fahrzeug-Auftragssteuerung
[13] illustration based on Kleiß, J. [61]

The week schedules created by the sales department in IFA are transferred to the program planning department every Wednesday roughly four and nine weeks ahead of the completion week, for T5 and Amarok respectively. The following day the SONATA3[14] system sequences the orders within the week schedule for assembly based on several selection criteria. These criteria include the even distribution of characteristics such as right-hand drive cars or non-standard roofs (NSR), for example.

This distribution of orders provides for level utilization of capacities. SONATA3 subsequently divides the week sequence in five sequences; one for every working day of the calendar week. In spite of the creation of this sequence, the data from SONATA3 is only regarded as target day schedules for supply, production, and distribution. Nevertheless, the system also provides the worker-planning, in which the appropriate number of workers are assigned per team along the assembly line.

According to the preliminary day sequence each vehicle receives a vehicle identification number (VIN), which includes the target completion year, calendar week, and day of the week, along with a running number. The actual planned production sequences, however, are determined later as there is one more step in the planning process.

In this last step of planning, eight days prior to completion of the respective orders and three to four days prior to the start of body construction, the system FIS DISPO II creates the final sequence of orders for the assembly. Subsequently the system also determines the sequences for the other sections in production, as Figure 13 shows, using the assembly sequence as a reference. Note that the T5 body construction sequence deviates no more than 25 positions from the assembly sequence and that for the T5 the sequence for painting is identical to the assembly sequence. The body construction sequence differs from these two due to the selection criterion of wheelbase-grouping for the reduction of changeovers. After sequencing with FIS DISPO II, the sequences remain unchanged until production. For the Amarok there is just one sequence, but color-grouping is done in the day scheduling of SONATA3 already [14].

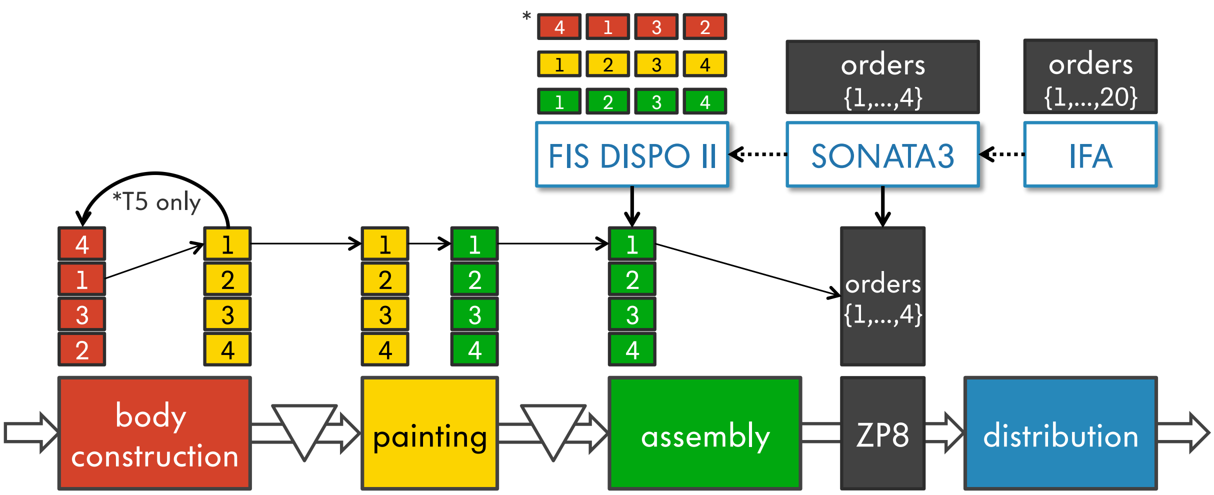

Figure 13: Scheduling and sequencing steps and systems

[14] from German: Soll nach Tagen (target per day)

In some cases, however, orders in the initial day schedule from SONATA3 are blocked and consequently omitted in the sequencing by FIS DISPO II. This may occur due to material unavailability, for example, but only occurred for about 20 orders in 2012. The different systems and their respective input criteria and output are summarized in Table 16 in Appendix D. The flow of planning and sequencing data and the corresponding systems are depicted in Figure 14 for a more thorough understanding of the planning with regard to scheduling and work dates.

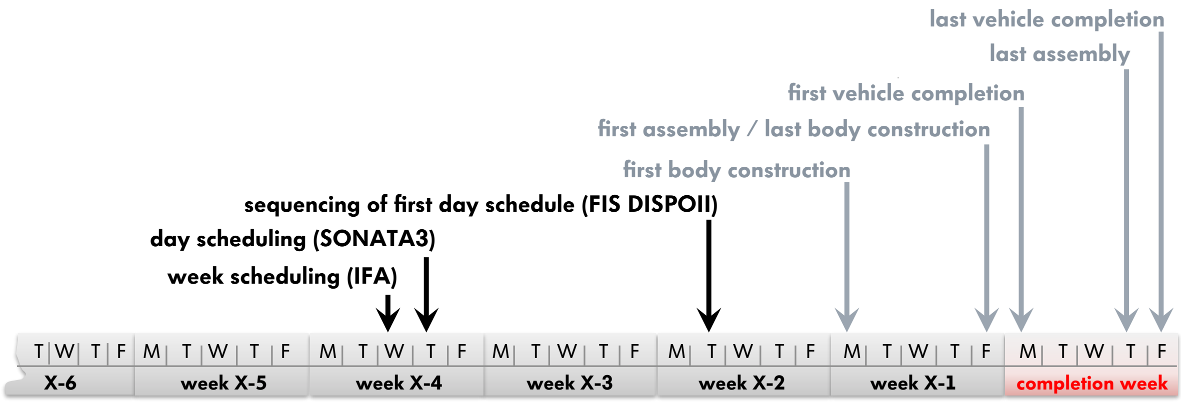

Figure 14: T5 scheduling and sequencing steps over time[15]

Note, however, that the week schedule and the week and day sequences from SONATA3 in the figure are for the T5 only as the Amarok's initial schedule is set nine weeks prior to completion. Consequently, information with regard to the required material can be issued four or nine weeks prior to completion, for T5 and Amarok respectively. The corresponding supply process is described in the following section.

2.4.4. Supply Process

Within the supply process one has to distinguish three different supply material categories:

- raw materials,
- purchase parts, and
- JIS components.

Raw materials are coils and sheet metal blanks of mostly steel, but also other metals such as aluminum, which are used for construction of the vehicle body. These are ordered three to four months prior to delivery due to the replenishment times. Quantities are thus based on forecast production values, while the standard range of coverage is approximately four weeks.

In the press plant, the raw material is transformed into production parts such as side frames, front lids, and roofs. This replenishment of production parts is stock-oriented and lot sizes usually cover about ten days, with an average range of coverage of about five days [15].

[15] illustration based on Freye [65]

Purchase parts are used in body construction, painting, and assembly. The net demand for these parts is calculated every weekend, where gross demands based on planned vehicle volumes, capacities, and scheduled orders from SONATA3 are calculated and compared to the stock values. Consequently the delivery quantities are determined using, among others, the batch quantities, replenishment times, and safety stock values. The resulting net demands are then transferred digitally to each of the roughly 970 suppliers every Monday morning. This information contains the batch sizes per part, delivery frequency, and delivery dates for the current week.

To cope with these short-term call-off orders, suppliers receive a frequently updated week-forecast six or nine months before delivery for the T5 or the Amarok, respectively. This delivery forecast (DELFOR) only has an accuracy of ±15%, due to which the suppliers also receive fixed order quantities per day in a delivery schedule, up to roughly three to four weeks before delivery. The exact delivery dates and quantities, however, are only set in the dispatch call-offs on Monday of the corresponding week, as changes may occur due to damaged parts, for example.

Within the new logistics concept of the Volkswagen Group (see section 2.2) the process for purchase parts, as described above, will slightly change. In the first step call-off orders from suppliers with a delivery frequency of two to three times per week are fixed over a period of up to nine days rather than four. This means an increase of one week for the suppliers to plan accordingly. In addition to this extended order period, the call-off orders will include the shipping dates rather than delivery dates [16,17]. An overview of the delivery schedule for the T5 can be seen in Table 2. As mentioned in the previous section, the Amarok's delivery schedule is frozen for eight weeks rather than three, and forecasts go as far as nine months into the future.

Table 2: Example of the level of detail for the purchase parts delivery schedule

T5: X + 3 to 6 months Amarok: X + 3 to 6 months		monthly demand	±15%	delivery forecast (DELFOR)
T5: X + 4 to 9 weeks		T5: weekly demands		
T5: X + 1 to 3 weeks Amarok: X + 1 to 9 weeks	Mon to Fri	daily demands	frozen period	delivery schedule
week X	Fri	daily demand *(fixed)*		
	Thu	daily demand *(fixed)*		
	Wed = day X	delivery *(fixed)*		
	Tue	delivered		
	Mon	delivered		dispatch call-off order for week X

In the current situation an area contract freight forwarder[16] picks up the purchase parts at the supplier according to above information and delivers them to Volkswagen Commercial Vehicles. Within the course of implementation of the new production system and the new logistics concept the principle of milk-runs[17] will be used wherever suitable to increase the frequency of deliveries per supplier while reducing the stock levels for the respective parts.

[16] A freight forwarder within a freight forwarding network which is responsible for a certain region.
[17] A transportation concept where multiple suppliers that are close to each other share one truck [12].

Some suppliers of purchase parts, however, receive their dispatch call-off orders by means of Kanban control. This process is thus slightly different from the previously described process for purchase parts. Instead of receiving weekly dispatch call-off orders, the Kanban suppliers receive a digital Kanban signal and have to replenish their parts in the stock accordingly.

JIS components are a special kind of purchase parts: pre-assembled components and modules that may differ greatly per vehicle and which are installed in assembly. They are supplied in the sequence of installation. For Volkswagen Commercial Vehicles the maximum delivery radius for direct delivery of JIS parts is set to 5 km. For the T5 4 of 27 JIS suppliers deliver their components from within this range, while 11 out of 20 do so for the Amarok. The suppliers situated further away make use of a third level logistics service provider (3PL) for the sequencing of their JIS parts. The JIS parts include, for example, the painted front-ends for vehicles with or without several technological options such as park distance control. The sheer numbers of options for such components make it impractical to keep them in stock. Ordering of JIS parts is thus based on the customer orders rather than forecast values.

This JIS supply process is somewhat similar to that of the regular purchase parts. Suppliers receive the delivery forecasts as described above, with ±15% accuracy to adjust their capacity accordingly. In addition, they receive a more detailed week schedule based on the completion day schedule from SONATA3. Eight days before completion of the vehicle, or six days before assembly, the suppliers receive the final planned assembly sequence from FIS DISPO II. In addition to this planning, suppliers also receive a note with the actual sequence of vehicles in body construction once production commences, which is usually two days before assembly starts. This provision of information is illustrated in Table 3.

Table 3: Overview of information transferred to JIS suppliers

checkpoint	A000 (SONATA3)	A500 (FIS DISPO II)	R100 (start body construction)	M100 (start assembly)
time to JIS call-off	~3 weeks	~6 days	~2 days	0
information transferred information deducible	vehicle identification number (VIN) vehicle completion date (target) approximate assembly date	VIN in plan-sequence (body construction) body construction date & sequence assembly date	VIN in actual sequence (body construction) assembly date	VIN in actual sequence (assembly) assembly date & time sequence number assembly sequence
	part and/or activity numbers (nr. of) parts of modules per vehicle			
frequency	every week	every day	every 20 to 50 vehicles	every vehicle

Most JIS suppliers ship their JIS components to a 3PL adjacent to the Volkswagen Commercial Vehicles plant based on the preview data. Additionally, the direct JIS suppliers within a 5 km range of Volkswagen that do not make use of the 3PL and deliver their components in sequence to Volkswagen directly. From direct JIS suppliers or the 3PL the goods are brought into their final sequence upon the final call-off. This final call-off for the parts is issued once the painted vehicle bodies start to move along the assembly line at M100 (see section 2.4.5). This means for T5 components the supplier (or the 3PL for the supplier) has from 48 minutes to roughly 400 minutes for the sequencing and delivery of parts in batches, depending on where the component is installed. The time for handling and delivery for most parts, however, is between 3 and 6 hours. For the Amarok the time for all components is between 2 and 6 hours [18].

One striking factor with regard JIS supply is the stock of JIS components at the 3PL. Though JIS supply is an advancement to just-in-time supply, all JIS suppliers for the T5 together use up a volume of almost 4000m^3 [19]. The reasons for this are the stock ranges defined per supplier. There stock ranges vary from 1.5 to 8 days for different distances between supplier and Volkswagen [20]. The causes for such large stock ranges for order-specific components are investigated in the process analysis in chapter 3.

Regardless, direct JIS supply is also proposed for distances greater than 5 km, which may drastically increase the number of direct JIS suppliers from the current 4 for the T5 and 11 for the Amarok [19,21]. In this case of long-distance JIS supply, the use of third level logistics service providers was omitted for the new direct JIS suppliers and they delivered in-sequence, creating the need for a reliable sequence preview within the production process even before assembly.

2.4.5. Production Process

The production process is a pure BTO process, with the exception of the press shop where material for vehicles are purely built-to-stock. Therefore the press shop has no direct influence on the production sequence and will thus not be considered in detail in the following; its material will be assumed available at all times. Additionally, the sequence of orders as set in FIS DISPO II should be maintained throughout the production process starting in body construction to ensure vehicles arrive at the assembly in sequence, where the respective vehicle components arrive in the actual vehicle entry sequence at the beginning of assembly. For the construction of the body, some parts are taken from the stock of production parts, while others are purchase parts. All body parts are welded or glued together to make the body shell. This shell is subsequently transported to a buffer between the body construction and painting lines.

In the paint shop, the body shells are prepared for further processing, primed, painted, and sealed before the T5 enter the large automated storage and retrieval system (ASRS) with direct access[18] to the bodies. The Amarok, however, flows to assembly according to a FIFO principle without an intermediate stock. From here, assembly pulls the bodies over the assembly lines, after which they are tested and then handed over to the distribution department for loading and shipping.

The entire process for the T5, from body construction to handing over the finished vehicles has an average processing time of approximately 62 hours, while on average body construction takes about 13 hours and painting and assembly take 24.5 hours each [22].

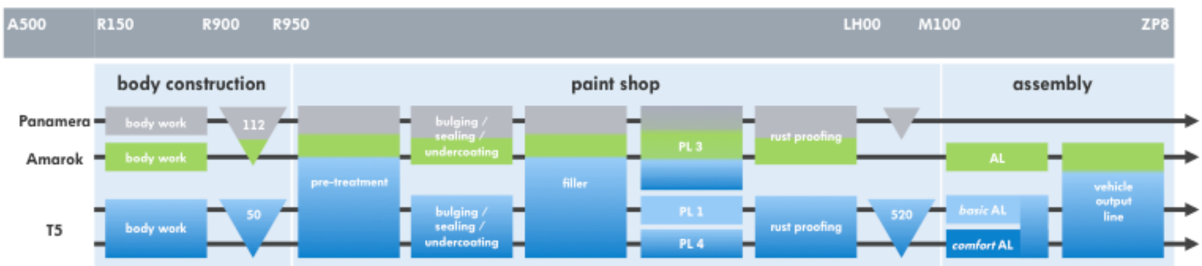

Figure 15: Overview of the production process and checkpoints

[18] the ability to directly access any piece of material in stock without the need for shuffling

Figure 15 shows a rough overview of the main steps within the three production departments, as well as the main checkpoints for monitoring and reporting. Even though this diagram shows some parallel structures, there are additional parallel structures that only become visible when going into further detail.

Body Construction

In body construction, the production sequence is valid right from the beginning of body construction, at counting point R150, meaning that the built-to-order production starts here and that all body shells of T5 and Amarok belong to a certain customer order. Body shells of the Panamera, however, may be switched after production in the plant in Hannover in case they are identical.

The last step of this sub-process is the transfer of bodies to the intermediate stock. This is separated for Transporters on the one hand, and Amarok and Panamera on the other. While the latter is a six-lane mix bank[19] (MB) with a total capacity of 92 vehicles and an ASRS with 20 slots, the T5 body stock is a 50 vehicle MB with a bypass. These stocks can reestablish the sequence of vehicles to a certain degree and are also the starting points for the painting process.

Painting

In the paint shop the vehicle flow is then split in two; one for the T5 and one for both Amarok and Panamera. Amarok, Panamera, and some T5 bodies are routed via a multi-model painting line (PL), while most T5 are painted on two dedicated painting lines; though PL 1 is only for white Transporters due to its age and quality. Quality issues result in rework, which occurs in boxes in case it is impossible to complete on the designated areas along the production line. In the case of severe quality issues, the vehicles may even be routed through the entire painting process again.

In the last step the painted Multivan and Transporter bodies are stored in the ASRS with 520 slots and direct access, while the Panamera bodies are resequenced and subsequently shipped by train to Porsche in Leipzig for further assembly. As mentioned earlier, the Amarok is transferred to assembly directly due to the absence of an ASRS for the pick-up truck.

Assembly

The last sub-process of production is the assembly. Vehicles are assembled in the sequence as planned in FIS DISPO II as much as possible. Some changes may occur due to restrictions of consecutive characteristics such as a second sliding door for the Transporter delivery van, and some changes occur due to the unavailability of cars at the right time due to unplanned prolongation of, or disturbances within, the upstream processes. Since the production sequence is very important both for balancing of workload in assembly and the sequential supply of order-specific components, the reasons for longer throughput times and disturbances within the upstream processes are investigated in the process analysis in chapter 3.

[19] a set of parallel lanes for storage, typically operates a first in, first out principle

While the Amarok assembly takes place on a single assembly line (AL), the T5 assembly has different parallel lines. Due to the substantial number of different configuration options, from basic delivery van to highly equipped Multivan, the work effort for Transporters differs greatly. This is the reason for the separation of flows and the creation of an assembly line *basic* for Transporters and an assembly line *comfort* for Multivans, which are later rejoined. If necessary, rework is done before the vehicles go into irrigation[20], and again if necessary, rework. The last step before completion is final inspection, where vehicles receive their ZP8 and thus completion status. [23].

After completion the vehicles are transferred to the distribution department. Some vehicles, however, actually receive an additional treatment even after the end of assembly in the so-called business unit for special vehicles (BUS). This applies to, for example, police and emergency vehicles, but also taxis, Multivan Business and California, and special industrial vehicles. Note that Amaroks get their ZP8 status after the BUS, while T5 get ZP8 status before the BUS and are subsequently blocked for shipping while in BUS treatment, if applicable [24].

2.4.6. Distribution Process

The distribution department, Volkswagen Logistics, receives a week schedule for the cars with their destinations four weeks before completion. After completion of assembly, once a vehicle passes ZP8, its final shipping data is transferred again. This shipping data includes the destination of the vehicle, as well as the means of transportation, which is determined by a centralized department of the Volkswagen Group in Wolfsburg.

According to this data, the vehicles are routed to the two means of transportation: railway carriages or semitrailer trucks. Trains are organized by Volkswagen and operated by different rail service providers that ship the carriages via a hub to their destinations. This means that carriages may only contain vehicles for one regional destination station, as the hubs only reassign entire carriages to different trains [25].

Shipping by means of semitrailer trucks differs slightly. Freight forwarders receive information on the number of vehicles to ship. Upon completion the vehicles are grouped per destination and the freight forwarders have two days to pick up the vehicles. If, however, there are just one or two vehicles for one destination, the distribution department may decide to either hold on to them for a little longer to wait and see if other vehicles for this destination are completed. Alternatively, they can be shipped without utilizing the entire capacity of a semitrailer. Of course, both alternatives are undesirable as they involve increased cost for either transport or storage, and sometimes even OTD penalties for excess throughput times [24].

Though it should theoretically be possible to plan the shipping of vehicles prior to completion, this is not done in practice. Hence, the results are vast requirements of parking area. Since a new pressing plant is in planning, the available area will be reduced and outside area will become even scarcer. Therefore, the reasons for the impossibility to plan are investigated in the process analysis in chapter 3.

[20] all T5 except Campers and Transporters with plastic window panes

2.5. The Just-In-Sequence Production Scheduling Concept

One goal of this thesis is to analyze and evaluate the influences of the order sequence from a logistics point of view. As mentioned in section 2.4.3, the production sequence and thus also the supply and distribution sequence are set at a rather early stage. This concept is known under various terms, as described in Appendix E, and will be referred to just-in-sequence production (JISP) in the remainder of this thesis.

JISP is defined by the German Association of the Automotive Industry[21] as the practice of planning both sequence and all characteristics of a vehicle during scheduling [26]. This corresponds to the practice at Volkswagen Commercial Vehicles, as described in 2.4.3, and many other companies within the automotive industry [12]. Ford implemented this concept in Saarlouis in 1989 [27], Audi in Ingolstadt in 1992 [28], and Volkswagen Commercial Vehicles in Hannover in 2005 [29].

Klug notes that the initial concept of JISP by Weyer [30] makes use of the push-principle rather than a pulling organization. This stands in contrast with the well-known Toyota Production System, and can be explained by the desire to make efficient use of the available capacity in the cost-intensive manufacturing departments of the organization. As Klug continues, however, in practice the concept is usually adapted and extended by a pull-control mechanism as in the case of Volkswagen. While customer orders are pushed through the body construction and painting processes, assembly and supply of components are pull-oriented. According to Klug, the basic modules of the JISP concept are the following:

- Stable order sequence in assembly
- Freezing of the short-term planning horizon (frozen-period)
- Customer-supplier relationships between the different subsections of production
- Assembly-driven pull-control
- Late order assignment[22]

At Volkswagen Commercial Vehicles, a stable sequence is maintained and the day schedule is frozen for roughly two weeks before body construction (see section 2.4.3). Also, there are customer-supplier relationships between the subsections, meaning that the assembly sequence is determined first. The second is the corresponding painting sequence, and at last the body construction sequence.

Moreover, there is assembly-driven pull control of components, although the body is not seen as a component, but a customer order-specific part already. Unfortunately this makes the late order assignment impractical, also due to number of possible body variants and the fact that the vehicle identification number (VIN) is engraved in the chassis early in body construction for T5 and Amarok.

Nevertheless, for the Panamera's comparably few variants (see section 2.1) late order assignment is common practice [14] and made possible due to the VIN being placed in assembly rather than during body construction [31].

[21] Verband der Automobilindustrie (VDA)

[22] the practice of assigning customer orders to vehicles as late as possible within the process

The immediate goal of JISP is the stability of the production sequence, which leads to a balanced and smooth production; a fundamental part of the Volkswagen Group production system. A stable sequence also supports the group's production system's principles of *pull* and *flow*, through the facilitation of pull supply processes on a large scale and the reduction of average throughput times of orders.

The strategies to accomplish stability, according to Meißner [32], are control of the sequence on the one hand, and restoration of the sequence on the other. The principles and methods to achieve the goal of stability of the sequence through the JISP concept, and their implementation at Volkswagen Commercial Vehicles, are discussed in detail in section 3.5.

While JISP has a very large impact on the supply of material in sequence, there is no visible influence on production parts or the supply of regular purchase parts. Production parts are produced to stock and are sourced long before the production sequences are determined, as mentioned in section 2.4.4.

With regard to purchase parts the complexity and variety of the parts is usually much smaller than for JIS parts. Consequently, regular purchase parts are delivered in homogenous batches and kept in stock according to standard and safety stock levels. Thus, the sequence of production influences the purchase parts stock levels only marginally, while the weekly and daily vehicle model mix volumes do have an influence on the stock levels and may cause fluctuations.

Accordingly, JISP influences the sequences in the different sections of production. However, as JIS parts are only used in assembly, the material flows of parts press, body construction, and painting remain unaffected by JISP.

2.5.1. Prerequisites

The implementation of the JISP scheduling concept requires fulfillment of a number of basic conditions, according to Klug [12]:

- Stability of logistic and production processes without capacity bottlenecks with balancing and smoothing (Heijunka) of production
- Use of intermediate stocks with direct access
- Reduction of the product variety
- Elimination of parallel lines for one model range
- Rework stations after assembly or integrated in the assembly line
- Adjustment of the material and information flows to the new system requirements

Of these prerequisites, not all are currently met at Volkswagen Commercial Vehicles. While stability of logistic processes without bottlenecks is given, and balancing and smoothing of production is already implemented as much as possible in a BTO environment, there are limitations with regard to the remaining prerequisites.

The production process suffers from disturbances that pose a need for improvement, regardless of JISP. In addition, the intermediate stocks between body construction and painting for T5 do not allow direct access of all vehicles. However, with the available MB with bypass, recovery of the initially planned sequence is at least possible to some degree for the T5.

Moreover, reduction of the product variety is not an option from a marketing point of view, as the variety is a strong unique selling point of premium car manufacturers. Parallel lines for the same model range emerged over time due to the need for larger capacities. Even though lines for the T5, for example, are already partially split for Transporters and Multivans. A complete separation on all levels, even for the three main model ranges T5, Amarok, and Panamera, is impossible on a short or medium term. The main reason for this is, among other things, the extensive capital investment required.

JISP is implemented despite its limited suitability for Volkswagen Commercial Vehicles in Hannover. The limiting factors do not strictly disqualify the plant for this scheduling concept, but pose a great challenge with regard to a successful implementation. This can also be seen in the following chapter, which deals with the controlling and monitoring of JISP. In the course of meeting the challenge, there are also a number of influences both of the different processes on the production sequence, and on the different processes as a result of JISP. These influences are discussed in chapter 3.

2.5.2. Controlling and Monitoring of JISP

For controlling of a process, one must be able to measure something and compare this to certain standards. With regard to the question of what to measure, there are different approaches. Weyer [30] defined a set of seven key figures for controlling of the sequence with regard to the maintenance of the sequence and both due-date and content wise performance. For the implementation of JISP, however, these key figures are rather impractical as Meißner [32] points out.

Instead, Meißner defines a set of different key figures split in two groups: planning key figures and control key figures. These key figures include, among others, the sequence deviation (SQD)[23]. The frequency distribution of the SQD provides a sound overview of frequency and intensity of deviations from the sequence over a period of time and will be treated in more detail later in this chapter. On the order level, the SQD can also be used to control resequencing within buffers and the flow of vehicles, for example in the case of large backlogs. A detailed description of the different key figures can be found in Appendix L.

Volkswagen mainly uses the sequence window reliability (SWR)[24] and the sequence performance (SQP)[25] over a production day (from 6 a.m. to 6 a.m.). The SWR is the percentage of vehicles not missing or delayed from the plan-sequence by more than a specific number of positions in the actual sequence. The specific number of positions is a tolerance value of sequence deviation and expressed as a parameter w of the sequence window reliability: SWR(w). The sequence performance is essentially the sequence window reliability with no tolerance, that is SWR(0) = SQP.

Note that this SWR only takes late deviations into account and neglects early production of orders, which are regarded to be a result of other orders' late production. Moreover, Volkswagen also creates frequency diagrams of the absolute sequence deviation (the difference between an order's position in the plan-sequence and its actual position) as described by Meißner. A fictional example of such a sequence deviation histogram is shown in Figure 16.

[23] in German: Reihenfolgenabweichung or Sequenzabweichung
[24] in German: Perlenkettenfenstertreue
[25] in German: Perlenkettengüte

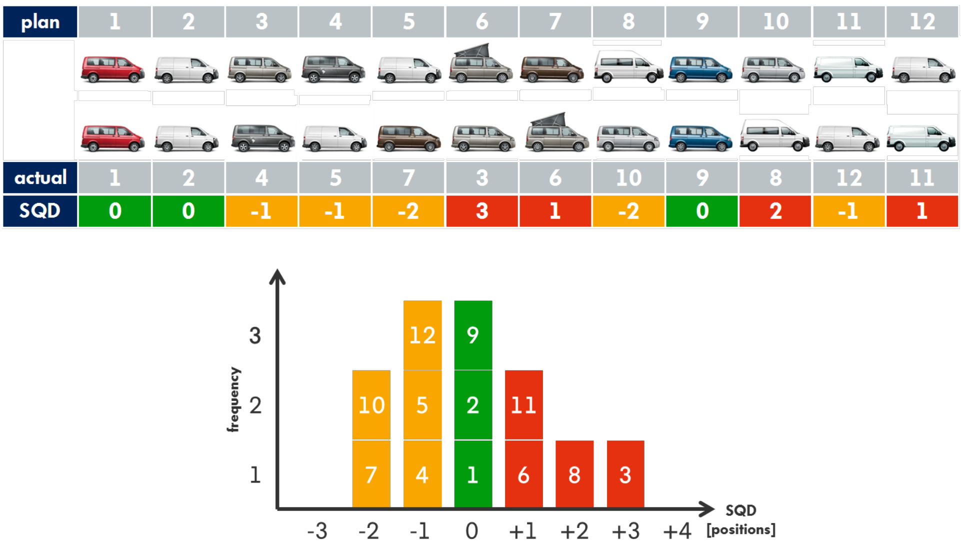

Figure 16: Fictional sequence deviation histogram

On the top of the figure, the plan sequence, actual sequence, and the resulting sequence deviation are shown. In this figure, the SQD's background color orange implies early production, while red implies late production. Note that in the evaluation period there are only three vehicles produced on time. One can also see that the SWR(2) is 91.7% or $\left(\frac{11}{12}\right)$, as only order 3 is delayed by more than 2 positions. Similarly, the SQP, or SWR(0), is 66.7% or $\left(\frac{8}{12}\right)$ due to orders 3, 6, 8, and 11 being delayed.

Volkswagen uses these two key figures and the sequence deviation frequency diagrams to evaluate the processes and determines the values based on the plan-sequence especially in assembly, as it is considered to be the most crucial and cost-intensive part of production. Moreover, JIS parts are installed in assembly only, making this part most interesting for investigations with regard to JIS supply.

2.5.3. Current Key Figure Values

JISP has been in place at the Hannover plant of Volkswagen Commercial Vehicles since April 2005. The use of the key figure sequence performance, however, was introduced in 2008 [33]. Figure 17 illustrates different key figure values for T5 at the different checkpoints in week 6 of 2013.

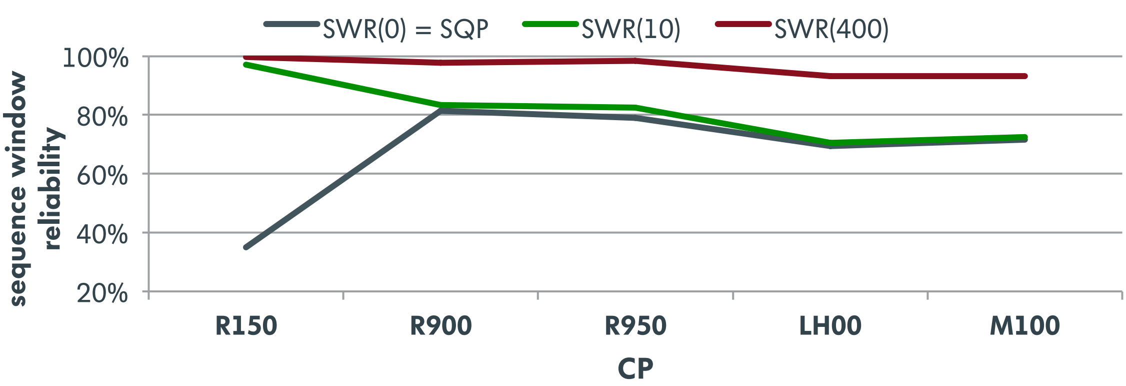

Figure 17: Assessment of different key figures and checkpoints (T5, week 6/2013)

The low value for the sequence performance SQP at the beginning of body construction (R150) can be explained easily. In the evaluation period a few orders were produced much earlier than initially planned and the result of a large number of orders being delayed by less than 10 positions, as the SWR(10) at the same checkpoint is 97.1%.

Figure 17 also shows that the FIFO buffer between the end of body construction (R900) and the beginning of painting (R950) is able to reduce the number of large deviations from the sequence, but actually increases the number of small deviations. The ASRS with elective access between the end of painting (LH00) and the beginning of assembly (M100), however, can restore the sequence much better for both large and small deviations from the plan sequence, as the increase of SQP and SWR(10) show. Nevertheless, the ASRS was unable to increase the SWR(400) for the same segment due to its low fill level of somewhere between 50 and 150 vehicles in the considered period.

These key figures also show the scrambling of the sequence between the different checkpoints. This deviation from the plan sequence poses a problem for the sequential supply of material, and is a result of deviations in throughput times. Figure 18 shows a histogram of the throughput times from the beginning of body construction (R150) to the beginning of assembly (M100).

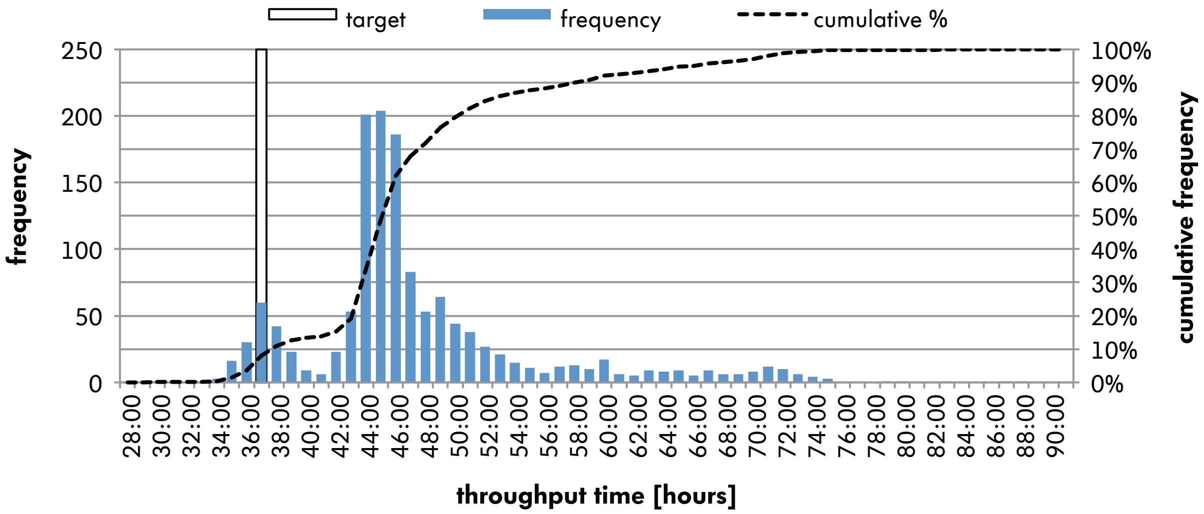

Figure 18: Throughput times from body construction to beginning of assembly (1383 T5, week 6/2013)

The large deviations in throughput times result from multiple factors, such as the variance of car bodies with special features that require additional work or rework outside the production lines. Detailed reports on the reasons for extended throughput times are unfortunately not available, but the distribution of throughput times in the figure suggests that the target is set for vehicles with no special features, and which do not require rework.

Proper control of a system requires, among other things, that the relationship between interferences and resulting behavior are known [36]. In this production system it seems as if this is not entirely the case, or some factors are neglected.

The following chapter will focus on analysis of the production system with its structures and influencing to provide a basis for a problem definition in chapter 4.

3. Process Analysis using the Delft Systems Approach

The processes described in section 2.4 are analyzed in this section of the report. For the graphical representation of the processes the Delft Systems Approach (DSA) will be used, which shows both material and information flows. It was initially described in 1975 in the Netherlands by in 't Veld as the *Delftse Systeemkunde* [37] and subsequently translated to English and extended to its current form as the Delft Systems Approach by Veeke, Ottjes, and Lodewijks [36] to meet additional needs for process analyses.

The system investigated is Volkswagen Commercial Vehicles with its main function to build vehicles in an environment of customers, society, the Volkswagen Group, and suppliers. For the production and thus output of vehicles the raw material, parts, components, and modules are required and thus flow into the system as an input. The Volkswagen Commercial Vehicles system is shown in Figure 19, which shows such a steady-state model – a model that considers one single flow of matter, or aspect.

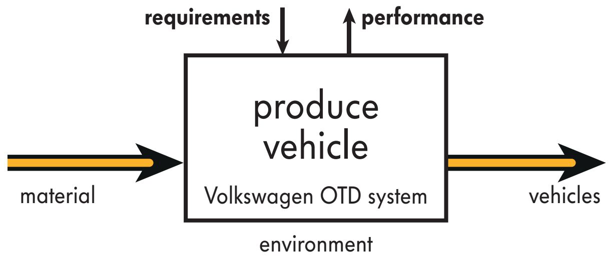

Figure 19: Main steady state model of Volkswagen Commercial Vehicles

3.1. Order-to-Delivery Process

In the description of the processes, however, it was shown that the production of vehicles occurs according to customer orders. Therefore, there is not only a material aspect, but also an important aspect of customer orders. Consequently, the steady-state model is insufficient for this purpose. Alternatively a different model, the so-called process-performance (PROPER) model of the Delft Systems Approach is used. It usually incorporates three aspects of order, material, and resources. However, the resource flow is deemed to not contribute to the goal of the thesis. Therefore, a simplified PROPER model with only order and material flow will be used in the following as a multi-aspect model. The specific multi-aspect model for Volkswagen Commercial Vehicles is shown in Figure 20. Note that the requirements are the grouped OTD goals from section 2.3. The performance is measured in terms of these goals as well.

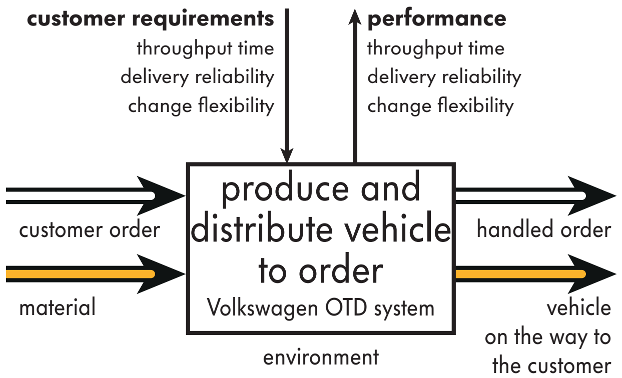

Figure 20: Main multi-aspect model of Volkswagen Commercial Vehicles

This figure's level of detail, however, does not provide for a thorough analysis of the process. Therefore, one has to zoom in one aggregation layer. That is, the level of detail within the system is increased to gain more insight into the processes within the system.

Figure 21 shows this more detailed model for the case at hand with two different sub-functions. Since these two sub-systems transform one aspect each, they are called sub-aspectsystems. While there is no exchange of information in the sense of the Delft Systems Approach between the two sub-aspectsystems, there are material flows in the form of production forecast and production orders into production and distribution and the flow of progress notifications into order handling. The model also shows a first-tier supplier[26], which includes 3PL for some suppliers. Additional upstream suppliers are not shown for the sake of clarity.

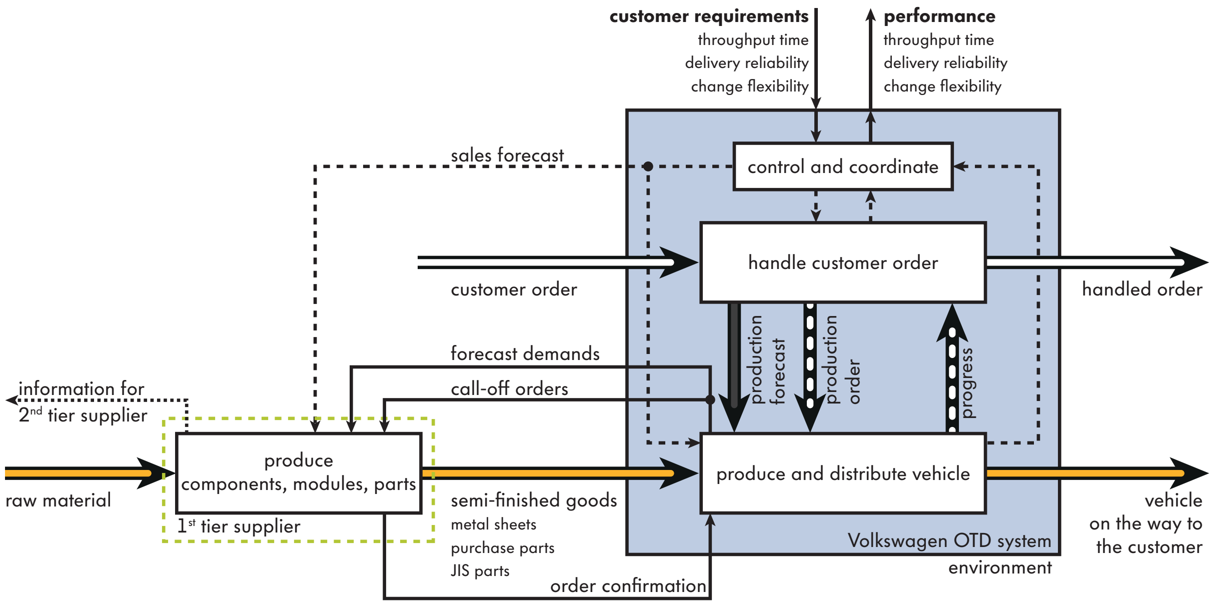

Figure 21: Main multi-aspect model with greater level of detail

The requirements have to be controlled and coordinated in order to provide the sub-aspectsystems with relevant sub-requirements that are appropriate to the aggregation layer of each entity. Thus, a superordinate function is necessary. Additionally, Volkswagen Commercial Vehicles provides suppliers with forecast values of the net demands for semi-finished goods and additional information with regard to JIS supply as described in section 2.4.4. The first-tier suppliers, on their part, provide Volkswagen with delivery information such as confirmations of the order quantities.

While the figure provides a good overview of the order to delivery process, the level of detail is still insufficient for a thorough analysis and identification of weak points within the processes. For this reason the transformation functions *handle customer orders* and *produce and distribute vehicles* are analyzed separately in more detail in the following chapters.

[26] a first-tier supplier, or primary supplier, is a company that provides parts and materials directly to a manufacturer of goods [64]

3.2. Sales and Planning Processes

For the analysis of the handle customer orders transformation function a steady state model, as described earlier in this chapter, rather than the multi-aspect model of the previous section is used. This enables the focus on specific analysis of each of the aspects. This transformation function comprises the sales and planning processes.

At the top of Figure 22 the requirements sales quantities and throughput times enter the system and are translated into more specific process standards. These standards are evaluated and adjusted according to OTD throughput times and sales quantities, which are additionally translated into performance values and fed back to the control function of the superordinate system.

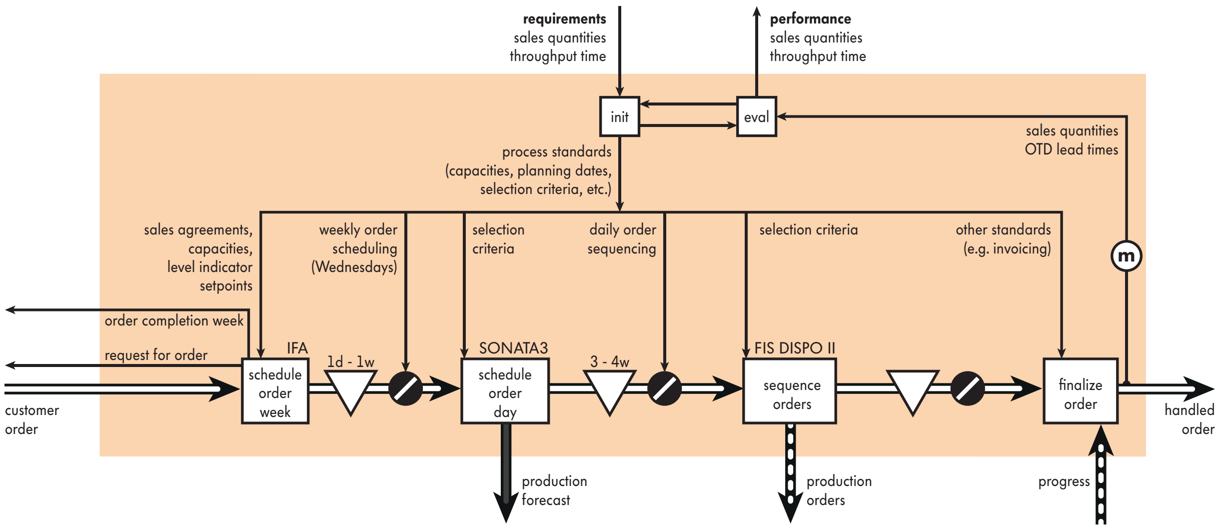

Figure 22: Steady state model of the current handle customer order transformation function

As described in sections 2.4.2 and 2.4.3, the customer orders are collected and scheduled. In a weekly order scheduling run the week packages of orders are scheduled per calendar week and subsequently split into day packages. These day packages are stored, but also transferred as a production forecast to the produce and distribute transformation function. Then the orders in the respective day package are sequenced production orders are issued. Until completion of the vehicles, the orders remain in the system and wait for finalization of the orders, including invoicing.

Note, however, that both scheduling and sequencing are based on the work efforts for assembly only[27]. Examples of these features are discussed in detail in section 3.3.

In section 3.2.1 the influencing factors and corresponding effects of the sales and planning processes on the sequence will be described. Section 3.2.2 shows the potential influences of JISP on these processes. Moreover, section 3.4 summarizes both influencing factors of processes on the sequence, and influences of JISP on the processes for the different sub-processes of the OTD process.

3.2.1. Influencing Factors and their Effects on the Sequence

While the sales process does not directly have an influence on the sequence, it is important what customer orders enter the planning and scheduling process. The influencing factors of this process on the sequence are described in the following.

[27] An exception is the wheelbase for the determination of the body construction sequence.

Planning and Scheduling Process

Due to the built-to-order character of production the **composition of customer orders** determines what features the cars to be built have,. For example, the recent shift in the ratio of Multivans of all T5 from 26% to 28% caused cycle times and thus the sequence to change. There is, however, no information available on how much it changed the sequence. But not only large changes, such as the models, cause changes in the way the production sequence is determined. Changes may also be caused by accumulation of features such as engines, or even a hitch.

In addition to the composition of customer orders, the sequence is also affected by **changes of customer orders**. Changes of restrictive features[28] occur rarely[29], but the sequence has to be redetermined in case they do occur. These two influences, however, cannot be taken into account in planning, as they are rather unpredictable.

Predictable effects of planning and scheduling are the different parameters that are used to determine the sequence in the first place. These criteria include the **level indicator setpoints**, which are in place to deal with different compositions of customer orders and to ensure that the contractually agreed delivery quantities with suppliers are met. These setpoints may cause single orders to be delayed by several weeks due to a single feature's capacity limit. The **selection criteria of SONATA3 and FIS DISPO II**, however, have the largest influence on the sequence. In SONATA3 the week packages are split into day packages, which predetermines the day on which a specific orders is supposed to be completed. FIS DISPO II sets the sequence, and its selection criteria are thus the most influential factors on the sequence. The **time-to-production of SONATA3 and FIS DISPO II** is also an influential factor, as changes within the specific input datasets are only possible up to these certain points in time. For example, an order cannot be assigned to a different day once it is scheduled in SONATA3 roughly eight days prior to production. Analogous, the sequence is frozen after sequencing in FIS DISPO II four days prior to production, and changes cannot be regarded after this point in time.

3.2.2. Potential Influences of JISP on the Processes

A holistic implementation of JISP, which includes all of the compliance with all requirements and prerequisites, has many potential influences on the different processes. This is also the case for the sales and planning processes, which are affected by JISP.

Sales Process

Regarding sales, one of the potential positive effects of JISP is **shorter lead times** for orders. Through less waiting times between the different processes the total lead times can be decreased and customers receive their vehicles earlier. Moreover, in the sequence the requirements of the different production sections are considered and production is more balanced, which supports the reduction of throughput times.

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[28] features which are used as selection criteria
[29] data on how often changes occur exactly is not available

The throughput times, along with the one-piece flow striven for, also provide for an **higher delivery reliability**; internally and eventually also externally towards the customer. The shorter lead times even have a positive influence on another factor, namely the reduced number of orders in progress and thus capital employed, according the Little's law[30]. This cost reduction can lead to either a **lower product price or larger return on investment**.

Nevertheless, there are also negative effects of JISP on the processes of both sales and planning and scheduling. Within sales, there is a **reduced timeframe of changeability for orders**, as scheduling and sequencing mark the points in time at which little or no changes are possible.

Planning and Scheduling Process

Within planning and scheduling there are some adverse influences of JISP. That is, scheduling and sequencing require increased efforts. On the one hand in form of the necessity for **determination of order processing times per production section**. These processing times can then be used to determine the throughput times in the different sections and provide for ideal arrival times at the sections. On the other hand, the **balancing and grouping of characteristics**, or selection criteria, is required to create the balanced distribution of work in the sections and to take restrictions with regard to changeovers into account.

Additionally, the provision of data for suppliers, which produce just-in-sequence, also requires **early freezing of the sequence** several days before production. The exact number of days depends among other factors on the suppliers' production, the distance, and the delivery frequency.

3.3. Supply, Production and Distribution Processes

The analysis of the supply, production, and distribution process is more complex than that of sales and planning due to its vast amount of communication structures. Figure 23 shows the production and shipping as described in section 2.4, with function control including the measuring of results and translation to performance values. Moreover, the figure depicts the data exchange with suppliers with regard to the production process.

On the top of Figure 23 one can see the requirements for the transformation function produce and distribute vehicles. The requirements are formulated in the superordinate OTD system's control and coordination function and include production quantity, delivery reliability, and throughput times.

These requirements also imply the performance figures, which the transformation function needs to report back to its environment, the superordinate system. Function control, in terms of the initiation and evaluation blocks, translates above requirements into process standards, which are omitted in the figure for clarity reasons. Moreover, the SQD is calculated from the difference between plan and actual sequences and consequently evaluated. This evaluation takes place for the SQD at different checkpoints in production, as well as the total throughput times and delivery reliability after shipping.

[30] number of elements in system = arrival rate × lead time [73]

Note that dashed thin lines represent sequence data, while solid thin lines represent the remaining data. Thick lines represent material flows, where dashed thick lines denote order-specific material flows.

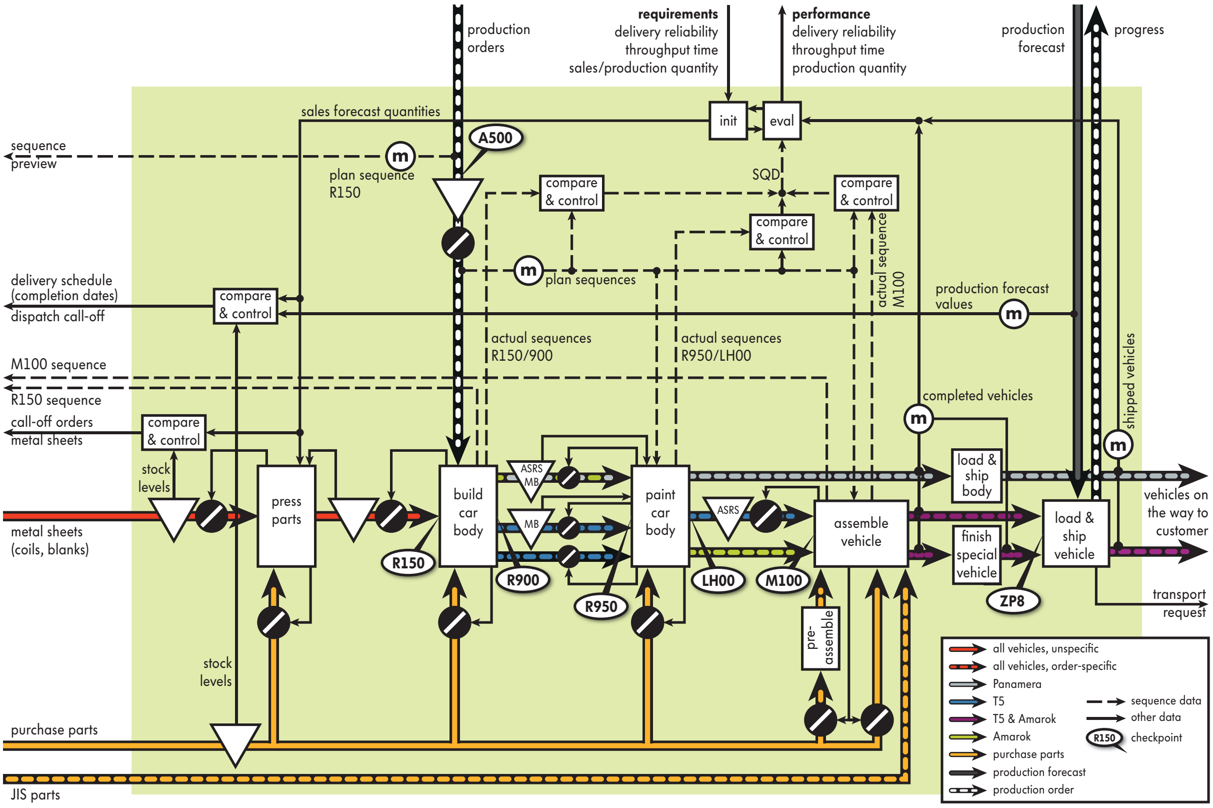

Figure 23: Steady state model of the produce and distribute vehicles transformation function

Production orders enter at the top left of the steady state model, and are stored in the order buffer before they enter body construction. The production orders then pass the production process together with the respective incomplete vehicles. Upon shipping the handle customer order transformation function also receives the completion notice as a progress report, which is used for invoicing of the customer. Also note that the planning data from SONATA3 only provides information for shipping and, as Figure 23 reveals, is used for ordering of purchase parts.

The model also shows that the sales forecast data is used to calculate net demands from available material and gross forecast demands to order metal sheets. For JIS modules, however, the process is different. Based on the forecast daily volumes from SONATA3 and the preview sequence from FIS DISPO II, suppliers produce the JIS modules and ship them according to the call-off orders issued at the beginning of assembly. Additional information for the supplier in terms of the sequence is issued in body construction at R150 as a preview for the JIS call-offs.

Quantitative data helps to assess shortcomings in these steps from a logistics point of view. For this reason the JIS supply and deviations from the plan sequence and schedule are analyzed. Regarding supplier scheduling, two JIS suppliers are investigated: FICOSA International and Faurecia.

While FICOSA International schedules its production of rear view mirrors nine to 13 days before the JIS call-off, Faurecia schedules their production of door linings only five to nine days before the JIS call-off. Both suppliers, however, schedule production based on the vehicle completion date targets from SONATA3, which they receive 14 to 18 days prior to the JIS call-off. According to these dates the suppliers calculate back what the dates in assembly are and thus when their components will be used. This calculation, however, only uses average throughput times per model, which are identical for all vehicles per model regardless of different throughput times. Table 4 illustrates the production scheduling of these two JIS suppliers.

Table 4: Scheduling of JIS suppliers FICOSA International and Faurecia

work days to JIS call-off	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
information	target vehicle completion dates (weekly, 14 to 18 days before JIS call-off)												plan sequence R150 (daily)				actual sequence		JIS call-off
checkpoint	A000												A500				R100		M100
FICOSA International safety stock: 3 days						scheduling *(weekly, 9 to 13 days before JIS call-off)*									production	shipping delivery			3PL sequences
Faurecia safety stock: 3 days										scheduling (weekly, 5 to 9 days before JIS call-off)					production	shipping delivery			3PL sequences

Note that both suppliers maintain a safety stock range of three days at the 3PL. This safety stock seems very high for JIS components, but can be justified by the inaccuracy of the data used for scheduling of component production. The target completion dates and thus dates assumed for assembly may differ greatly from the actual dates in case large process disturbances occur. The plan and actual values may even be several days off-target, which results in missing parts or vastly increased stock levels and ranges. This has happened in the past and directly resulted in delays, special transports, and missing parts for door linings, as well as stock ranges rising to as much as 10 days in the case of rear view mirrors. These results also increased the auxiliary procurement costs, caused delays of deliveries, and the necessary efforts for changes of the suppliers' production. Ultimately, it also resulted increased product costs and reduced the maximum delivery quantities for the door linings of Faurecia. Figure 24 reveals the inaccuracy of this data, caused by the later changes in sequencing and the section-specific optimization of processes.

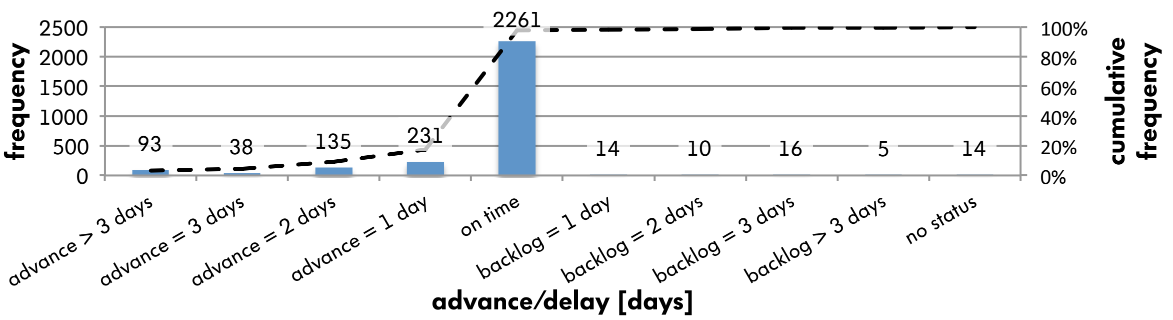

Figure 24: Adherence at M100 to the calculative daily volume from SONATA3 in week 9/2013 (2817 vehicles in total, 497 produced in advance, 45 produced with delay)

This seemingly early production may not be actual advance production due to occasional changes in production numbers. Yet, the result is low adherence to the target completion schedule suppliers calculate with to plan their production. This, in return, may result in the inability to produce the vehicles in the planned sequence, as delivery of JIS components from direct JIS suppliers is done relatively short before assembly.

As described earlier, the distribution department gets information from the schedule created in SONATA3. The information includes the model variant and destination, but not other transport-relevant data such as the size and height of vehicles that may differ due to special features. In addition to the target completion dates from SONATA3, the distribution department only receives a completion notice for vehicles that pass ZP8. Hence, the distribution department is also affected negatively as advance production deprives the distribution department of the ability to plan with the initially scheduled vehicles.

Because planning ahead is impossible in the distribution department, freight forwarders receive information for distribution of vehicles based on this completion notice of vehicles and have two days' time to pick up the respective vehicles after a request for transport is issued. This request, however, is only issued when a certain number of vehicles per destination are finished. This means that vehicles distributed via freight forwarders usually stay in the inventory lot for at least two days. In fact, the average inventory time for truck-shipped vehicles is 2.19 days. Due to the variance in throughput times there is no possibility for the distribution department to plan ahead with the data currently provided.

Moreover, the extensive scrambling of the sequence as described in section 2.5.3 has a rather large impact on the different processes as described in the following chapter. To get to the root cause of this problem it is important to investigate the influences in the production processes carefully, as that is where scrambling develops: in body construction, painting, and assembly.

The instability in the production process resulted in roughly 4% of all T5 deviating less than 50 positions from the plan sequence at M100 in week 6/2013. Figure 25 shows the corresponding sequence deviation histogram.

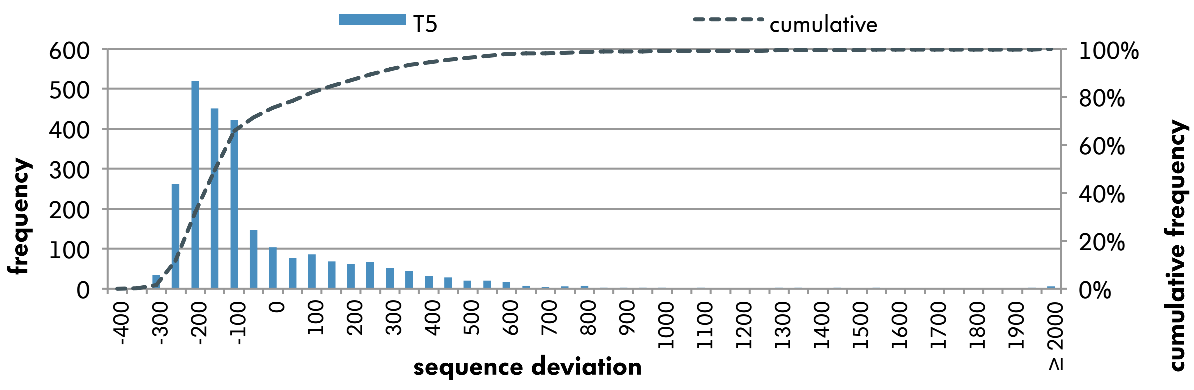

Figure 25: Sequence deviation histogram for M100
(2642 T5, week 6/2013)

Thus, within the production process, scrambling occurs very frequently. Nevertheless, one can observe an accumulation of delays for certain features, which cause prolongation of throughput times. In section 3.2 it was pointed out, however, that these throughput times are not considered in planning and scheduling. Therefore sequence delays occur more frequently for vehicles with these special features than for vehicles without them.

For example, T5 with NSR require manual labor in body construction and accounted for 9% of all T5 in week 6/2013. In this period they had a median delay of 306 sequence positions, for which Figure 26 shows the SQD histogram at R900. Note that the median value for T5 with standard roof is 46 sequence positions early.

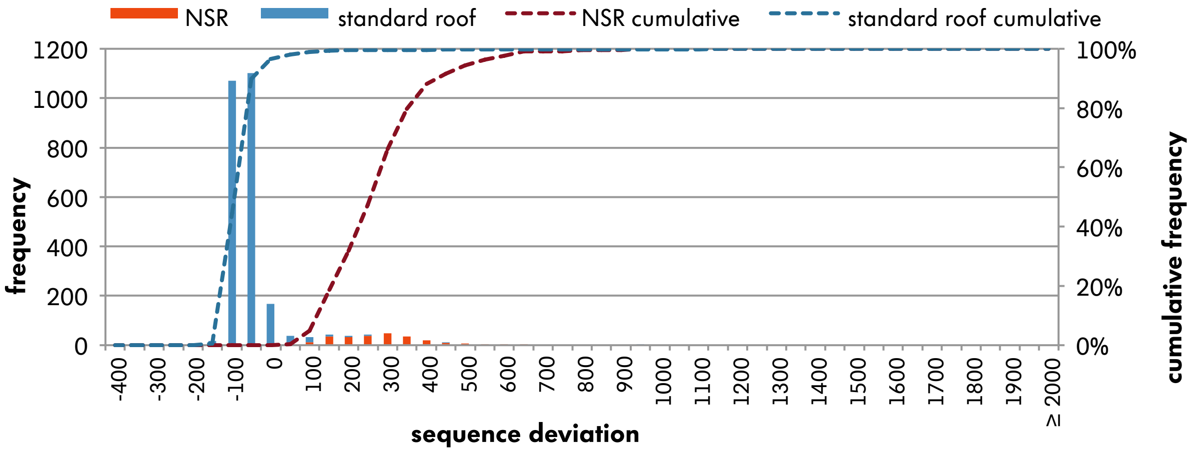

Figure 26: Sequence deviation histogram for T5 at R900 with indicated roof type (2632 T5, week 6/2013)

Larger periods of time are difficult to display in the SQD histograms. Instead, the boxplot in Figure 27 shows the sequence deviation in terms of median, quartiles, and outliers per day. The median values per day are all positive (delay) with a mean of 97 positions, and the 50%-interval covers early vehicles in only in two of the cases shown. Moreover, on the negative (early) side, there are only very few vehicles to be found. The thin blue lines extend to the outermost occurrences within 1.5 times the interquartile range (IQR). The asymmetries of these lines per day imply a similar shape of the distribution as in Figure 26. For the days around March 20th, 2013, the sequence shift is exceptionally high as a result of an employees meeting within the period and the corresponding delay.

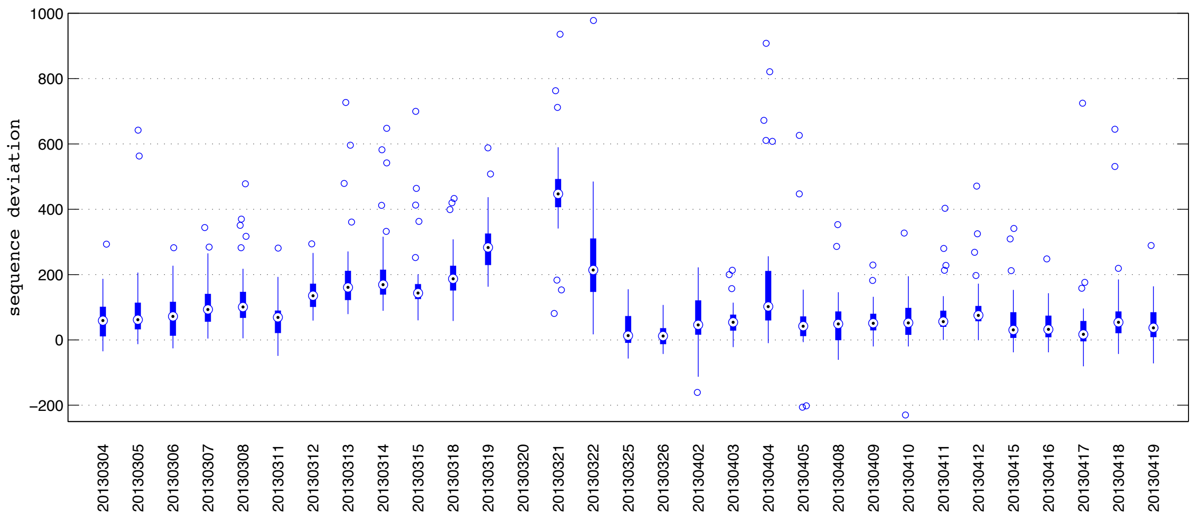

Figure 27: Boxplot of the sequence deviations for T5 with NSR at R900

Note that there are numerous outliers with delay, while there are very few that are early. The figure shows the data for R900, at the end of body construction, while the boxplot in Figure 60 in Appendix H for R150 shows how little the sequence deviation for vehicles with NSR was initially. It thus becomes obvious that the SQD for these vehicles at LH00 and M100 are strongly influenced by the SQD that develops in body construction.

Another feature neglected in scheduling are double-layer paint (DLP) colors. These are special, mostly light, colors such as yellow and white tones that have to be painted twice due to the opacity of the paint. Though usually vehicles with DLP colors represent just 1% of all T5 (week 6/2013), greater problems may occur when corporate clients order a large number of cars for their fleet, as the median SQD for the 1% in 6/2013 was a delay of 98 positions at LH00. The median sequence deviation for the remaining T5 without DLP color was 115 positions in advance. Figure 28 shows the corresponding SQD histogram with indicated type of paint. Also note that all of these vehicles had standard roofs and were painted on PL 4.

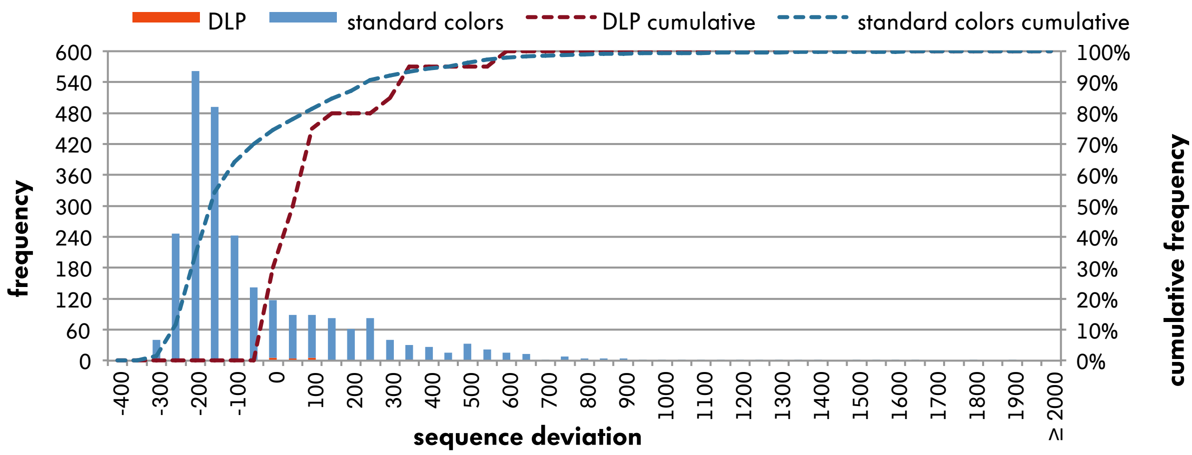

Figure 28: Sequence deviation histogram for LH00 with indicated DLP colors (2481 T5, week 6/2013)

Moreover, the boxplot for these vehicles in Figure 65 in Appendix H suggests that over larger periods of time there are hardly any vehicles that are early at the end of painting. While the ranges fluctuate severely over time, almost all vehicles are delayed, thus causing the large share of vehicles with DLP colors delayed at LH00 and M100.

Additionally, when looking at SQD histograms for specific painting lines such as Figure 29, one can see that most vehicles that move over PL 1 have large delays, while there are few that are early or on time. In week 6/2013 10% of all T5 and 40% of all white T5 were painted on PL 1 with n median of 386 positions delay within the sequence. The median on PL 3 was 36 positions delay, while on PL 4 vehicles were 133 positions early. Note that there were no DLP colors and only 1% of all vehicles moving over PL 1 had a NSR.

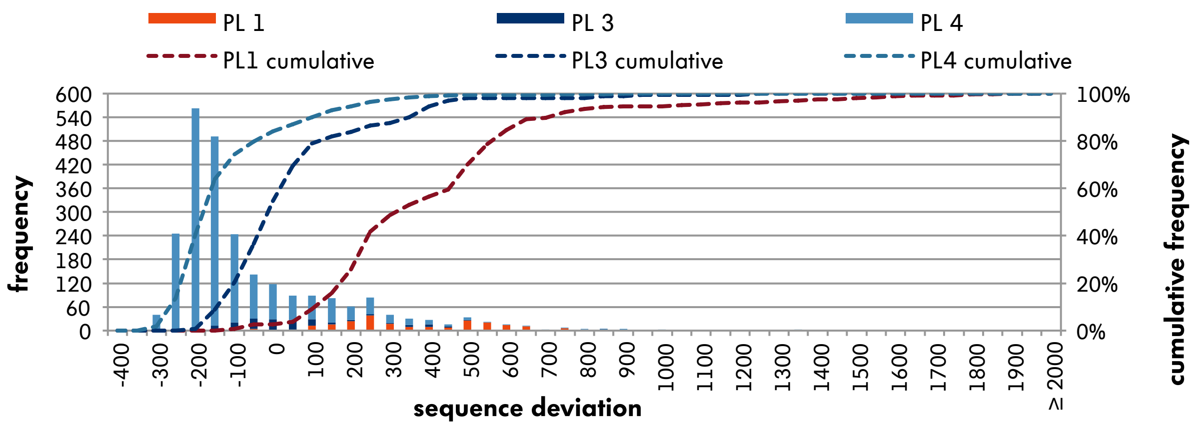

Figure 29: Sequence deviation histogram for LH00 with indicated PL (2481 T5, week 6/2013)

Also note that the dashed line indicating cumulative percentages for PL 3 and PL 4 look somewhat similar, while the dashed line for PL 1 differs greatly from the first two. This indicates the large difference in scrambling of vehicles on PL 1.

Additionally, the boxplot in Figure 68 in Appendix H shows that the vehicles painted on PL 1 are hardly ever in sequence, even over larger periods. While there is a large degree of variance, there is some sort of baseline for the daily medians at a delay of approximately 200 sequence positions.

Consequently, the two features NSR and DLP, as well as painting on PL 1 cause large degrees of sequence scrambling. To put their sequence deviations into perspective Figure 30 illustrates all T5 of week 6/2013 that neither had a NSR nor DLP, and which were not painted on PL 1. This accounts for 81% of the vehicles, for which the median is 136 sequence positions early. In total, those T5 with any of aforementioned features exhibit a median SQD of 262 positions, which shows the large discrepancy between vehicles with and without special features.

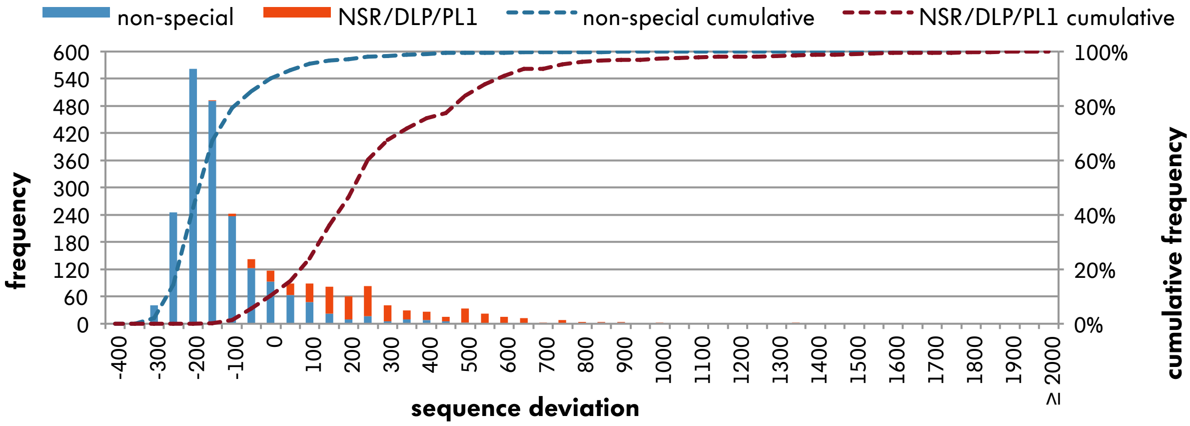

Figure 30: Sequence deviation comparing T5 with and without NSR/DLP/PL1 at LH00 (2481 in total, week 6/2013)

In section 3.3.1 the influencing factors and corresponding effects of the supply, production, and distribution processes on the sequence will be described. Section 3.3.2 shows the potential influences of JISP on these processes. Moreover, section 3.4 summarizes both influencing factors of processes on the sequence, and influences of JISP on the processes for the different sub-processes of the order-to-delivery process.

3.3.1. Influencing Factors and their Effects on the Sequence

While the distribution process does not have any influences on the sequence, the supply and the production processes do have several influences on the sequence.

Supply Process

One of the more complex and unpredictable influences in the supply process is the **unavailability of parts**. Whenever parts for specific orders are unavailable, the corresponding orders have to be blocked and retained until the parts become available. Otherwise, a vehicle might move along the assembly line and miss the engine, for example. Installing the entire engine later is near impossible. Reasons for the unavailability of parts are, among others, incorrect master data in the system, incorrect information on stock levels, or simply parts gone missing.

Special cases of unavailable parts occur whenever inbound or in-house transport and handling cause **damaged shipments**. Another case is whenever suppliers fail to ship the correct components, which results in **incomplete shipments**. In these cases the missing parts are ordered and shipped as soon as possible to allow for re-release of the order to production. Oftentimes, however, the sequence is already scrambled before the missing parts become available for production.

Predictable influences of the supply process on the sequence are the **supplier capacities**. These are contractually agreed within certain margins and are taken into consideration in, for example, the week scheduling by means of the level indicator setpoints. Suppliers prepare for a possible deviation of their own capacities from the agreed quantities of maximum 15%. Whenever they are asked to produce even more, they may not be able to do so. In these cases all orders with these features have to be postponed until the material becomes available again.

Production Process

As mentioned earlier, the production process also has several influences on the sequence. Among the unpredictable ones is the **unavailability of personnel**, which may occur due to an accumulation of worker illness, for example. In the case of some areas having much less personnel available than required, the cycle times have to be adjusted. With parallel lines, this means that the output initially planned cannot be adhered to anymore; the result is scrambling of the sequence. In some special cases – such as for manual labor on high roofs – it may even be necessary to block vehicles before they enter production until a sufficient number of employees is available.

Another influential factor are special **quality checks** as opposed to standard quality checks on the production line. There are special quality audits in which unpainted bodies or assembled vehicles are checked intensely. These audits are random samples, and there are certain quotas per day and per model that have to be checked. Note that the distinction of models also separates Multivans and Transporters with different quotas from the assembly onwards [38]. Vehicles are fed back into the production flow later, which results in sequence scrambling.

Quality-related blocking has a similar effect and occurs whenever quality issues with certain features of a vehicle occur repeatedly, such as a color in painting or a component in assembly. The vehicles with these features are blocked before they enter the corresponding section in production until the issues have been resolved and thus the sequence is scrambled. The same result of sequence scrambling can be seen for **process disturbances**, such as unplanned idling of certain machines on parallel lines. All vehicles waiting in line before the idle machine are delayed by the duration of the machine idling, while vehicles on other lines move on as planned.

A similar problem occurs whenever **rework** is necessary. This happens frequently in the painting department, for example, where vehicles may be treated in spot-repair boxes or, if the damages are severe, vehicles have to pass through the entire painting process again. Rework in painting alone is necessary for as much as 50% of all vehicles due to the high quality requirements.

Extreme cases of insufficient quality can lead to yet another influence on the sequence: **scrap**. This is sometimes the case for parts of vehicles only, such as doors, and occurs for about 1.1% of all T5[31]. In 0.2% of the cases[32], however, entire vehicles are scrapped. The corresponding orders are delayed severely and have to be fed into the production flow from the very beginning.

While **late order assignment** is a method to reduce the scrambling intensity, it does generate sequence scrambling voluntarily in the case of scrap or delay of vehicles that have not been assigned to a specific order. While scrapping of one vehicle causes delay of one order only, switching and reassignment of vehicles to different orders delays at least two orders. At Volkswagen Commercial Vehicles late order assignment is used very frequently, but exclusively for the Porsche Panamera bodies.

Despite the fact that most influences on the sequence have to do with delays, **advance production** may also lead to changes in the sequence. This happens, for example, whenever some sections perform much better than expected and process more vehicles than initially planned. As production is not stopped whenever the orders scheduled for one day are completed, those scheduled for the following day may be produced in advance. This, however, is only possible for those vehicles for which the material is available; the discrepancies result in sequence scrambling once more. Unfortunately, data on the occurrence of advance production is not available.

In addition to above unpredictable influences of the production process on the sequence, there are also several predictable ones. One of these is the use of **different shift models per section**, due to which capacities differ between the different sections. While this does not influence the sequence directly, the fill levels of buffers between the sections fluctuate greatly and so does the ability to cope with intense sequence scrambling. Consequently the fill level of the ASRS for T5 between painting and assembly may fluctuate between 520 and 350 vehicles within 24 hours, even if all sections are working as usual.

This brings up the next influence, the **fill levels of stocks**. The more vehicles are stored in an intermediate stock with random access, the more intense the resolvable deviations from the planned sequence at entering of the stock are. The number of vehicles in stock, however, also determines the waiting time and thus the total lead time of orders. Currently the target fill level of the ASRS for T5 between painting and assembly is 400, meaning that theoretically sequence delays by up to 400 positions can be recovered.

Moreover, not all stocks have random access, and thus the **control of stocks** is another influential factor on the sequence. Pure FIFO stocks are unable to influence the sequence, but MB with several FIFO lanes may change the sequence. An example is the stock between body construction and painting for T5, where vehicles can only enter the stock in a FIFO lane or bypass the stock entirely. The standard deviation of the sequence deviation positions between the two corresponding checkpoints before and after the stock was reduced from 130 to 116 in week 6 of 2013.

[31] 1.06% of all T5 were scrapped partially between 04-03-2013 and 19-04-2013
[32] 0.19% of all T5 were scrapped entirely between 04-03-2013 and 19-04-2013

Another influence with regard to the production layout is the use of **parallel model-specific processes**. This is the case for the Transporter and Multivan, for example. While there is no separation of their production flow in body construction, there is some separation in painting and even a strict separation in assembly with a difference in cycle times of 26 seconds between the lines[33]. These parallel structures may also result in unwanted changes of the sequence. Notably, this can cause a difference of the mean median SQD of 324 positions for specific models[34]. Moreover, the Amarok assembly cycle time is currently 321 seconds and thus more than twice as long as for the two T5 assembly lines.

Analogous to parallel model-specific processes, there are also **parallel model-unspecific processes**, such as in painting, where Multivans are painted on two different painting lines. In this case one can even observe a difference of the mean median SQD of 394 positions[35]. These parallel model-unspecific processes may even include conveying, as the distances between the parallel lines may be different and intermediate buffers may differ in size.

Additionally, **different conveying technologies** on parallel segments, with different speeds, may also provide for changes in the sequence, though these last two examples have a negligible impact in practice at Volkswagen Commercial Vehicles.

3.3.2. Potential Influences of JISP on the Processes

As stated in section 3.2.2, a holistic implementation of JISP, which includes all of the compliance with all requirements and prerequisites, has many potential influences on the different processes. This is also the case for the supply, production, and distribution processes, which are affected by JISP in many different ways.

Supply Process

Positive effects of JISP on the supply process include **reduced stock levels and times** in storage for parts. The reduction of storage times and thus stock levels is a result of parts and components being replenished according to customer orders. This means, that slow sellers may be reduced or even eliminated in some cases and safety stock levels may be reduced.

An additional step is the **extension of the JIS supply radius** from the current 5 km, as there is a great certainty of which components will be needed when, as long as JISP is implemented well. This extension of the distance between supplier and Volkswagen enables more suppliers[36] to deliver their goods directly, and storage area may be reduced markedly.

[33] Cycle times are 128 and 154 seconds for Transporter and Multivan AL, respectively [14]. Joint lines for the T5 have a cycle time of 89 seconds [72].
[34] 324 is the difference between mean median SQD per day for all T5 at LH00 and mean median SQD per day for all T5 with DLP at LH00 for week 6/2013.
[35] 394 is the difference between mean median SQD per day for all T5 at LH00 and mean median SQD per day for all T5 painted on painting line 1 at LH00 for week 6/2013.
[36] There are currently 15 direct JIS suppliers for T5 and Amarok together.

A requirement for the supply process is, however, that there are **early and accurate forecasts for suppliers**. If these were missing, the security of supply was endangered and the full positive potential of JISP on the supply process, as described in the previous paragraph, could not be harvested. Additionally, a **high degree of integration of suppliers** is required to cope with exception handling and inaccuracies in the supplied data. Negligence of this need may, again, result in missing parts and adverse effects on the production sequence.

With JISP, it is also important to note that **costs for changes in the supply sequence** in terms of exception handling may rise, as the frequency of exception handling is more likely to increase than to decrease if the risks of, for example, JIS supply over larger distances were taken. All in all, there is a much greater **sensitivity to disturbances in the sequence** that requires the aforementioned integration of suppliers to cope with changes to prevent a bullwhip effect in the supply chain. This may occur due to fluctuations of delivery forecast values updated sparingly. Moreover, it is especially crucial for large deviations that not only have severe influences on multiple suppliers, but also on different levels of the organization.

Production Process

The production process is also influenced positively by JISP. Due to the number of potential influences, those on the material control sub-process will be treated separately from the remaining production process. Among the positive influences on the production process is the **smooth and balanced production** in assembly, which is a result of the detailed planning and scheduling. These take the requirements of production into account and provide for evenly distributed work efforts over time. This facilitates a good atmosphere on the shop floor, prevents hectic production and thus supports the quality of both work and product. Smooth and balanced production also supports another potential positive effect of JISP: the **reduction of throughput times**. The reduction results from the distribution of work over time, as line stoppage occurs less frequently in a more balanced production.

The improved delivery reliability, as described in section 3.2.2, is not only visible externally. There is also **higher internal delivery reliability** whenever customer-supplier-relationships are in place between the different sections. Each section tries to satisfy the requirements of the downstream process rather than solely optimizing its own process, and thus the delivery reliability increases. At the same time the optimization of the production sequence results in **high total utilization of the sections**, because there is one production sequence optimized for all sections. The section-specific optimization is subordinate to the overall process optimization, with the result of improved performance of the entire production process.

Once JISP is implemented and performs well with little sequence scrambling, there is also the possibility of **reduced size of intermediate stocks**. The task of intermediate stocks is to allow for restoration of the sequence, as well as decoupling of the processes. As soon as the sequence performance is good continuously, that is with few instances of large sequence deviations, there is a reduced need for a large number of vehicles in stock. Nevertheless, the decoupling of processes is a very important reason to keep intermediate stocks in place, even with perfect sequence performance.

JISP can also have a positive impact on the mindset of workers. Since disturbances of the sequence cause disturbance of the process, one can observe an **increased quality-awareness of employees**. Parts are handled with better care, product quality increases, and process performance improves due to a decreased need for exception handling.

There are also a number of requirements with regard to the production process, such as **highly stable processes**. If this process stability is not given and a lot of disturbances scramble the production sequence, the use of JISP can be inefficient and ineffective. Up to a certain degree of disturbances, however, the implementation of JISP is useful. In these cases, and even for processes with little disturbances only, the use of **ASRS for restoration of the sequence** is required. The few cases of processes that do not need an ASRS for sequence restoration are close to perfect, can cope with little disturbances, and its sub-processes are more or less restriction-free. In all other cases where restrictions are in place, the restoration of the sequence remains essential for the harvesting of potentials with regard to – among others – the material control process.

Material Control Process

This potential for material control includes **reduced picking efforts**, as JIS components are supplied in the production sequence and do not have to be sequenced for assembly. Ideally the parts are even supplied in racks that can be transported to the production line. Another benefit is that there are **fewer damages due to fewer handling steps**. If the components do not have to be repacked or sequenced, there is a smaller chance of damages to the material. Consequently, exception handling for parts that are damaged through handling occurs less frequently.

Additionally, there are **reduced search efforts** in picking, as more components can be shipped in-sequence, stocks are less abundant, and the required components can be found more easily. Moreover, the greater certainty of which components will be needed at the different installation locations allows for a **reduction of transport paths** for material control. Without JISP there may be excess material, which has to be transported back to the warehouse. The implementation of JISP helps to transport only those parts to the line, which will actually be used on short notice.

Nevertheless, there is also a requirement for the implementation of JISP with regard to material control. In case of disturbances of the sequence, one has to be able to provide the components to the assembly line that are actually necessary. Therefore, **exception handling processes** need to be in place for the reordering or resequencing of parts, for example. These processes are essential to ensure the suitable supply of parts, as the perfect implementation of JISP is near impossible as a result of process disturbances.

Distribution Process

As the most downstream process, the distribution process benefits greatly from JISP. The increased certainty of which vehicles have to be shipped in the near future allows for **reduced inventory levels and inventory times**. Freight forwarders can be informed timely about the to-be-shipped vehicles rather than after vehicle completion only. Moreover, if the sequence performance is sufficient, a detailed planning of shipments is made possible to reduce inventories even further.

The optimization of shipping does not only have beneficial impacts on the inventories, but can also result in **optimized freight charges**. Shipments for certain regions can be combined where possible because the distribution department knows which vehicles will be completed in the near future.

3.4. Summary of Influencing Variables

Due to the number of interrelations between processes and sequence described in sections 3.2 and 3.3, it is hard to keep track of all the influences of the processes on the sequence, and the influences of the sequence on the processes. Consequently, Figure 31 shows the influences on the production order sequence – denote by SQ in the figure – for the planning, supply, and production processes. The bottom half of the figure shows predictable influences, that is, those that can be taken into consideration in planning. The figure's top half shows unpredictable influences one cannot consider in sequencing.

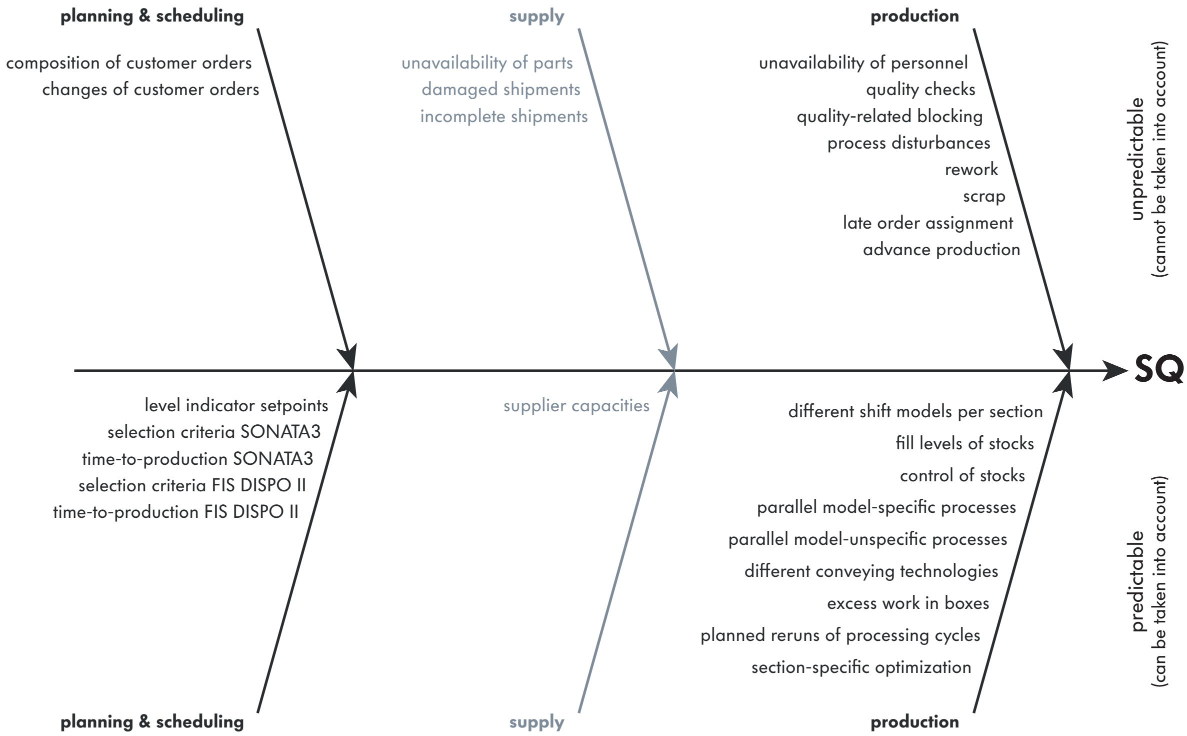

Figure 31: Influences of the processes on the sequence

In addition, Figure 32 illustrates the potential influences of JISP on the processes of sales, planning, supply, production and its materials management part, and distribution. Moreover, the effect on the OTD process of transparent processes is shown to the right of the graph. The transparency of processes is one of the most important positive effects of JISP. Deviations from the regular course of action can be identified quickly and efficiently if the correct control and reporting structures are in place. Subsequently, the mitigation of damages and the prevention of excessive problems can be facilitated.

The top half of Figure 32 shows positive potential for the processes, while the bottom half illustrates both potential negative effects and prerequisites that need to be fulfilled in order to use JISP effectively and efficiently.

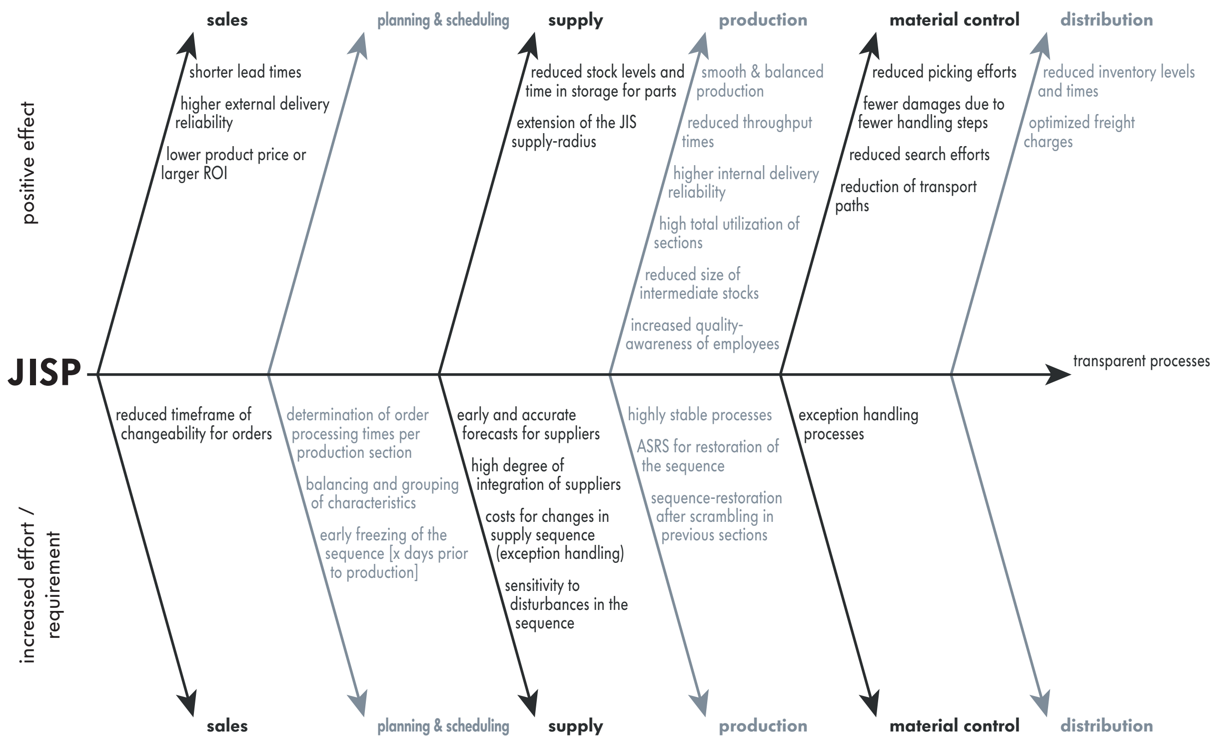

Figure 32: Potential influences of just-in-sequence production on the processes

In the following section the degree and quality of the implementation of JISP at Volkswagen Commercial Vehicles in Hannover are described and analyzed to provide a basis for the definition of problems within the OTD process.

3.5. Current Degree of Implementation of Just-in-Sequence Production

While Volkswagen Commercial Vehicles uses JISP for their plant in Hannover, one cannot speak of a perfect implementation. Of the principles and methods for control and restoration proposed by Meißner (see section 2.5) only a few have been implemented completely. These fully implemented ones include frozen planning, clocked FIFO flow, and that the main flow determines side flows, as well as the synchronized provision of material.

Of the remaining principles, standardization and segmentation, and process stability and short quality control loops, and a restriction-free production flow are implemented partially. In the case of Volkswagen Commercial Vehicles the standardization is rather undesirable, as the diversity of products is a unique selling point of the company. For parts where this is possible, however, standardization is in fact implemented, and the production is segmented to allow for special vehicle treatment outside the regular production line.

Process stability aims at the prevention of defects with the goal of a stable sequence and is only a given in parts of production. Short quality control loops are in place, but rework is done outside the production line in most cases. Regarding restriction-free production, there are restrictions on both body construction and assembly, though in body construction only the wheelbase needs consideration. In assembly a number of restrictions are in place to enable balanced and smooth production. Though the assembly of Amaroks was approached as restriction-free, it turned out to be impossible to maintain this principle here.

Among those principles not implemented are sequence discipline and the cost-by-cause principle. Production continues if the sequence is flawed, and the different sections in production are not held liable for the scrambling of the sequence. Moreover, the production flows cannot be considered transparent, as one is unable to determine whether a vehicle on the line is delayed or early in the sequence; neither in the production flow, nor on screens at the measuring points along the production line.

For control of the sequence a number of methods are implemented completely, while others are implemented only partially. Among those implemented completely is FIFO control as a means to control the sequence. With the exception of intermediate buffers between the production sections a FIFO flow is maintained in production, with the goal to adhere to the respective input sequence, though there is some sequence scrambling due to other reasons discussed later in this section. Another fully implemented method is the synchronous provision of material to production, where parts – for which this is possible and advantageous – are pre-assembled in sequence or provisioned in sequence to the production line.

Partial implementation of methods for control of the sequence can be seen in the synchronous parallel processes, for example. Though ideally the parallel flows are synchronous, they are actually synchronous in a few places only. In painting they are, theoretically, but the disturbances on the process cause for large degrees of sequence scrambling anyway. Moreover, in assembly the cycle times for Transporter and Multivan are even different. This causes a great deal of changes to the sequence, even though the parts crucial to the sequence are installed before the production flows meet again.

The integration of quality checks in the production line is also partially implemented. There are quality checks that are carried out on the line, such as at the end of painting or at the end of assembly, but there are in fact several points in production where vehicles are extracted from the production flow for randomized testing. Similarly, some quality repairs are carried out within the confines of the production line, but whenever repairs are necessary which exceed the time available on the line, vehicles are repaired outside the line. This happens very frequently, especially in painting, and results in sequence scrambling.

Monitoring and visualization of the sequence is a means to create more transparency in the process. This method is, however, only used in terms of monitoring in logistics. This means that the goal of transparency is not achieved, and personnel in the sections of production with high manual labor are unable to act accordingly.

With regard to the methods for restoration of the sequence only first in sequence, first out (FISFO) control and physical resorting are partially implemented. FISFO control seeks to restore the sequence in buffers with elective access by selecting the lowest sequence number and thus the order that should be completed first. This FISFO control, however, is sparingly used in the ASRS between painting and assembly for the T5. Moreover, the FISFO control is restricted by the requirements of assembly, such as the distance in sequence positions for two vehicles with right-hand drive, for example. With regard to physical resorting some processes are in place. For the Amarok, however, there is no possibility of resorting between painting and assembly, which diminishes the chances of a much higher sequence performance.

The remaining methods proposed by Meißner are not implemented. Single line production is impractical for the T5, as the work efforts between Transporter and Multivan differ greatly. Even more so, there are three different sequences that move over one filler line in painting, which creates a large risk of sequence scrambling there.

As mentioned earlier, sequence restrictions are in place as well. Though there had been efforts to work without restrictions for the Amarok, assembly was unable to cope with the different work efforts that resulted from different models. Thus, restrictions are now in place for both Amarok and T5 and prevent proper FISFO control.

Line stoppage as a method for control of the sequence is entirely neglected at Volkswagen Commercial vehicles. The dependence of downstream processes on the continuous flow of production is too large and the utilization drop that results from line stoppage is deemed inacceptable.

The sequence restoration methods not implemented include visual resorting or late order assignment. Even though there may be the possibility for late order assignment for the Amarok with its 16 body variants, the possibility of doing so has not been considered in the past. Another method specifically used to increase the possibility of late order assignment is variant management. Its purpose is to generate variants as late as possible in production to maintain a relatively small number of basic vehicle models for a longer period of time. This way orders can be switched more frequently, giving the late order assignment method more flexibility to restore the sequence.

Early order release is another method for sequence restoration, which is not implemented. It seeks to release orders with features that inhabit longer average throughput times earlier to account for the resulting delays in favor of the downstream processes. These increased throughput times may occur due to, for example, different types of roofs that require manual labor for the T5.

Additionally, Meißner also proposes reserve bodies as substitutes for large delays caused by scrap, for example. This method is supposed to reduce large delays, but Meißner also points out that this is only useful for bodies that are very frequently used. Lastly, there are no emergency concepts in place that ensure material availability once the delay of a specific vehicle is known. There is, however, currently also no necessity to have this method in place in Hannover, as the supply of material is only requested once the vehicle is irrevocably in the FIFO process of the assembly line. Nevertheless, with the possible implementation of long-distance JIS[37], there is no way around such emergency concepts.

[37] long-distance JIS denotes the direct JIS supply from suppliers outside Volkswagen's immediate vicinity

goal		
stability of the sequence		
strategies		
control of the sequence		restoration of the sequence
principles		
• frozen planning • clocked FIFO flow • standardization and segmentation	• sequence discipline and cost-by-cause principle • transparent production flows • main flow determines side flows	• process stability and short quality control loops • restriction-free production flow
methods		
control		**restoration**
• FIFO control • single line production • synchronous parallel processes • elimination of sequence restrictions	• quality checks in the production flow • immediate quality repairs • stop of production in the case of scrambling • synchronous provision of material • monitoring and visualization of the sequence	• FISFO control • physical resorting • virtual resorting • variant management • early order release • reserve bodies • emergency concepts

implemented not implemented partially implemented

Figure 33: Implementation of principles and methods for just-in-sequence production[38]

Figure 33 provides an overview of the implementation of principles and methods for control and restoration of the sequence according to Meißner. It also gives an overview of the small number of fully implemented methods and principles for a control and restoration of the sequence, which suggests a number of possible fields for improvement to achieve a large stability of the sequence.

The description of the different processes and the process analysis provide a basis for the problem definition which follows in chapter 4 and will be used to select and mitigate a number of identified problems in chapter 5.

[38] illustration based on Meißner [32]

4. Problem Definition

From the process description in section 2.4 and the process analysis in chapter 3 a number of problems in the OTD process of Volkswagen Commercial Vehicles in Hannover can be derived. Even though several different problems were identified, this thesis focuses only a selection thereof. The selection process is described in section 4.1, followed by the problem definitions for the selection.

4.1. Problem Selection

The problems described in the following sections are a selection of the entire set of problems that emerged during process analysis. All problems are categorized and summed up in Appendix G, where the unselected problems are also described briefly. For the selection of problems a set of criteria was determined. The criteria to support the selection process in this thesis are the expected economic benefit and cost for both generation and implementation of a solution. Per problem category these criteria and the corresponding expected values of very low, low, medium, high, and very high – according to the researcher's evaluation – were given and are shown in Table 5. A detailed table of all identified problems can be found in Appendix K.

Table 5: Problems selected for mitigation

category	ID	problem	expected benefit	expected mitigation cost
information of JIS suppliers	1.1	forecast data for JIS suppliers	high	low
	1.2	lack of knowledge of JIS suppliers		
internal information	2.1	lack of information for distribution department	high	medium
	2.2	type of information for distribution department		
scheduling & sequencing	3.1	special vehicle bodies	high	medium
	3.2	multiple paint layers		
	3.3	throughput times of painting line 1		
	3.4	difference between the target and plan sequence		

The combinations of potential benefits and efforts for the first three categories of information of suppliers, internal information, and scheduling and sequencing suggest the highest expected cost-benefit ratio. Consequently, these three problem categories are treated in more detail in the remainder of the thesis and will be explained in more detail in the following sections. Chapter 5 introduces three different methods for improvement and describes their respective expectations. Evaluations by experts on the matter will be used to validate the different measures with quantitative analysis for assessment in the follow-up.

4.2. Problems in Information of JIS Suppliers

The description of the supply process in section 3.3 leads to two problem definitions. For one, the **(1.1) forecast data for JIS suppliers** is rather limited in its information content. Suppliers receive target vehicle completion dates, while these have little to do with the actual dates on which components are required. Accordingly, the vehicle completion dates should not be used for the scheduling of production, but rather as a first indicator for capacity planning.

A second, more significant problem with regard to external information is the **(1.2) lack of knowledge of JIS suppliers** about the planning and production at Volkswagen. The knowledge required for a sound and reasonable planning of production is not always a given due to the vast amount of information suppliers get and the level of explanation of this data. Additionally, the turnover of personnel at the supplier also results in a lack of knowledge required for a thought-out planning.

4.3. Problems in Internal Information

The information policy within the distribution process as described in section 3.3 leads to a **(2.1) lack of information for distribution** with regard to an accurate preview of the completion dates of vehicles. Planning ahead with the target completion dates is thus impractical for the shipping process and consequently omitted for all of the roughly 3,600 T5 and Amarok produced per week.

The **(2.2) type of information transmitted to the distribution department** leads to yet another problem. T5 that pass ZP8, but which are not ready for shipping due to special treatment in the BUS, are counted as being available for shipping and thus considered as capital commitment in distribution. The costs-by-cause principle is neglected and transparency in the process is limited. This holds for an average of roughly 7%, or 220, of all T5 that are produced per week [39].

4.4. Problems in Scheduling and Sequencing

In section 3.2 it is pointed out that within the planning process the processing times for different model variants are not taken into consideration. This results in large deviations of processing times from the target times and subsequently also in the sequence. These deviations in the sequence were described in section 3.3 in more detail by means of SQD histograms and boxplots for different characteristics. They included vehicles with NSR or DLP, but also vehicles painted on PL 1.

Accordingly, there is no feature-based calculation of processing times for **(3.1) special vehicle bodies** and thus no according change in the section-specific plan-sequence. This is the case for the Multivan California camper, for example. This variant has a NSR and some processing steps that require processing outside the production line. Nevertheless, the vehicles are treated in planning as if there was no additional effort necessary in production. Due to the large deviations from the sequence the supply of JIS modules can only be called-off once the vehicle actually enters the assembly line and the intended balancing of the assembly line is more difficult to accomplish.

A similar problem is the negligence of extended throughput times for DLP colors and their **(3.2) multiple paint layers** in planning. These double runs of the paint process results in scrambling of the sequence on the one hand, and longer throughput times for vehicles with and without DLP colors on the other.

Another weak point that causes the throughput times to rise the painting department is the **(3.3) throughput times of painting line 1**, which result in large deviations from the plan-sequence.

A last identified weak point in scheduling and sequencing is the **(3.4) difference between the target and plan sequence.** Though there is a sequence is created in the scheduling system SONATA3 roughly three weeks before body construction, the final plan-sequence is only determined in FIS DISPO II about four working days before body construction begins. The sequence introduced in SONATA3 is completely disregarded in all other processes and is just a way to determine the target day schedules. While most restrictions of the scheduling and sequencing systems are identical, there are additional ones for determination of the sequence in body construction and assembly in FIS DISPO II. This way the optimization of both body construction and assembly is ensured, but the sequence transmitted in SONATA3 is rendered useless for planning, internally and externally.

Figure 34 and Figure 35 show the selected problems within the steady state models introduced in chapter 3. Figure 34 reveals the two problem groups selected within the produce and distribute vehicles transformation function.

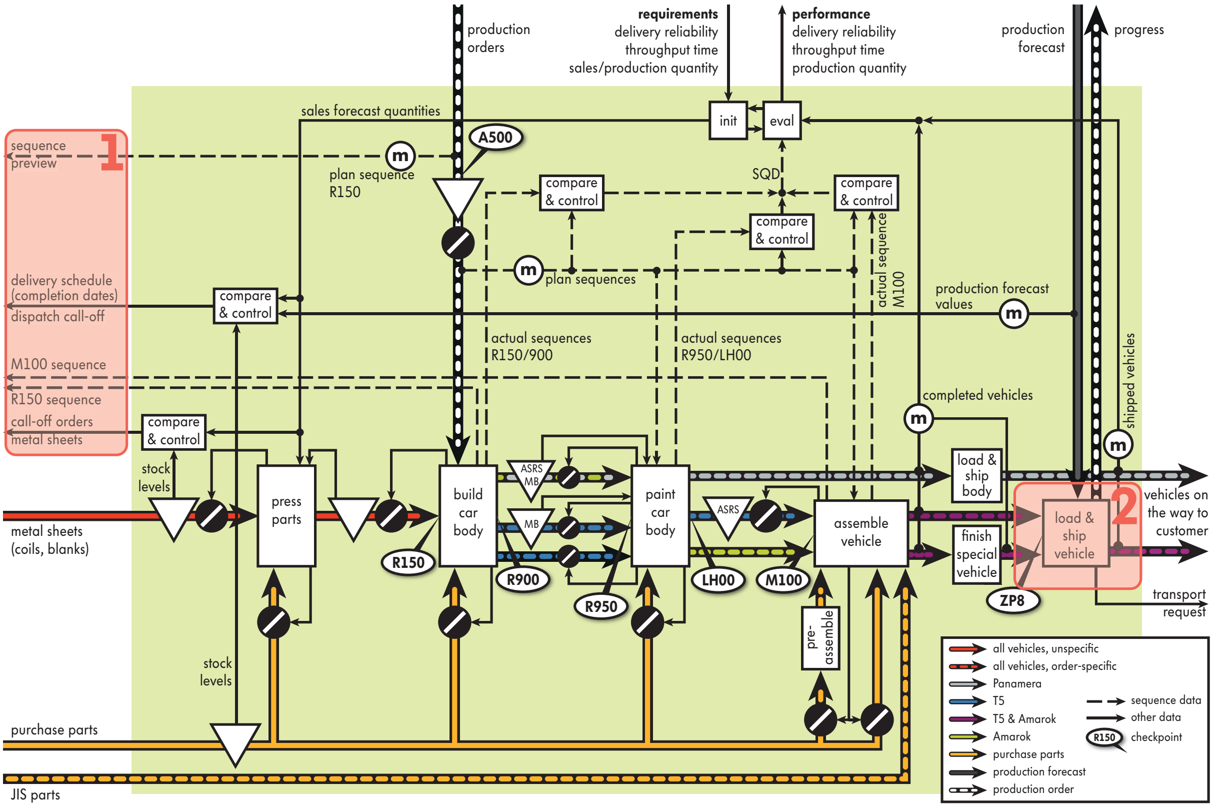

Figure 34: Identified problems within the produce and distribute vehicles transformation function

The third and last selected problem group is situated within the handle customer order transformation function, as illustrated in Figure 35, and – as mentioned earlier in this chapter – concerns the scheduling and sequencing of orders and the resulting production forecast and production orders.

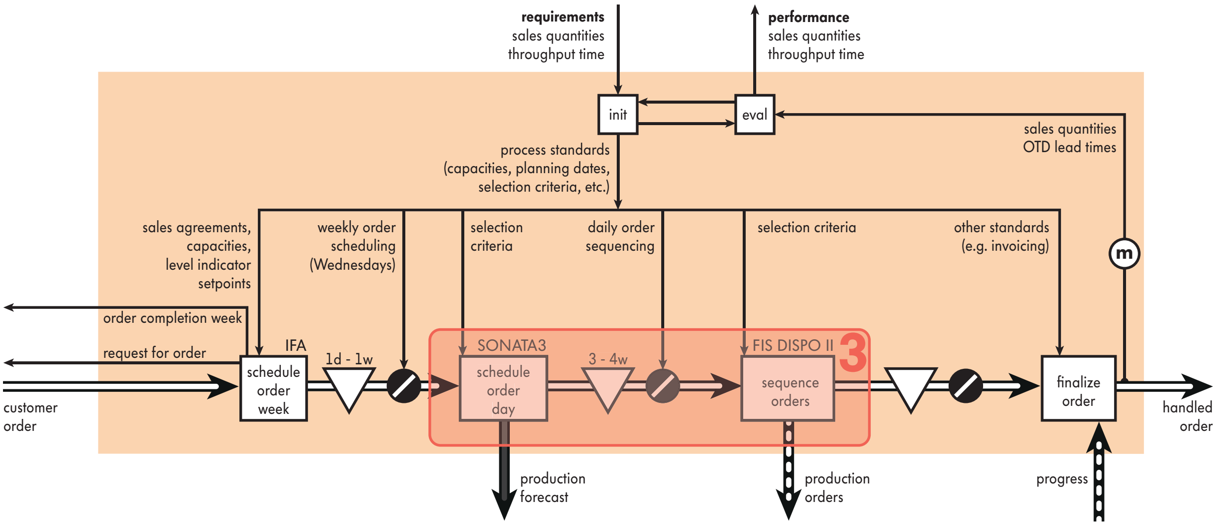

Figure 35: Identified problems within the handle customer order transformation function

4.5. Research Question

The process analysis in chapter 3 and the problem definitions on information of JIS suppliers, internal information, and scheduling and sequencing lead to a research question:

How can the logistics processes and process communication be improved to make the production of vehicles more efficient and effective with regard to the production order sequence and in due consideration of the current production processes?

In chapter 5 a number of approaches for problem solving are described and assessed with regard to their ability to improve the logistics processes at Volkswagen Commercial Vehicles.

5. Problem Solving Approach

The problems as defined in the previous chapter have to be mitigated in order to improve the process performance. In a first step the boundary conditions for the problem solutions are formulated. Subsequently potential methods for improvement of the specific problems are provided, along with the expected improvement and KPI for assessment of each solution. Following this are validations and assessments with regard to the specific KPI. Moreover, this chapter seeks to provide an approach to improve the current situation with concepts aimed at solving the individual problems or, if possible, multiple problems at once.

5.1. Boundary Conditions

The solution space of this thesis is restricted to the OTD system as introduced in chapter 3.1. This means that the solutions are within the sphere of direct influence of Volkswagen. Moreover, the solutions shall not include extensive physical restructuring of the production structure.

5.2. Methods for Improvement

During analysis of the processes a number of ideas for improvements emerged. These were discussed with different stakeholders and developed further following the discussions. The results are methods for improvement for the three problem categories as introduced in section 4.1. These methods include the

- information and coaching of JIS suppliers,
- provision of additional information for the distribution department, and
- integration of scheduling and sequencing functions with sequence-shifting.

The following sections will elaborate on the different measures, and provide the respective expectations and KPI. Subsequently the measures are discussed critically in the respective validation and assessment sections. Validation of the measures is done qualitatively, as the solutions were discussed and evaluated critically by experts of the respective areas in the corresponding sections.

For implementation of the proposed solutions regarding the information of JIS suppliers and additional data provision for the distribution department, new changes in the communication structure are necessary. These are added to the model as introduced in chapter 3. In Figure 36 the required changes for the information of JIS suppliers is emphasized in green, while changes for the measures with regard to the distribution of vehicles are illustrated in red.

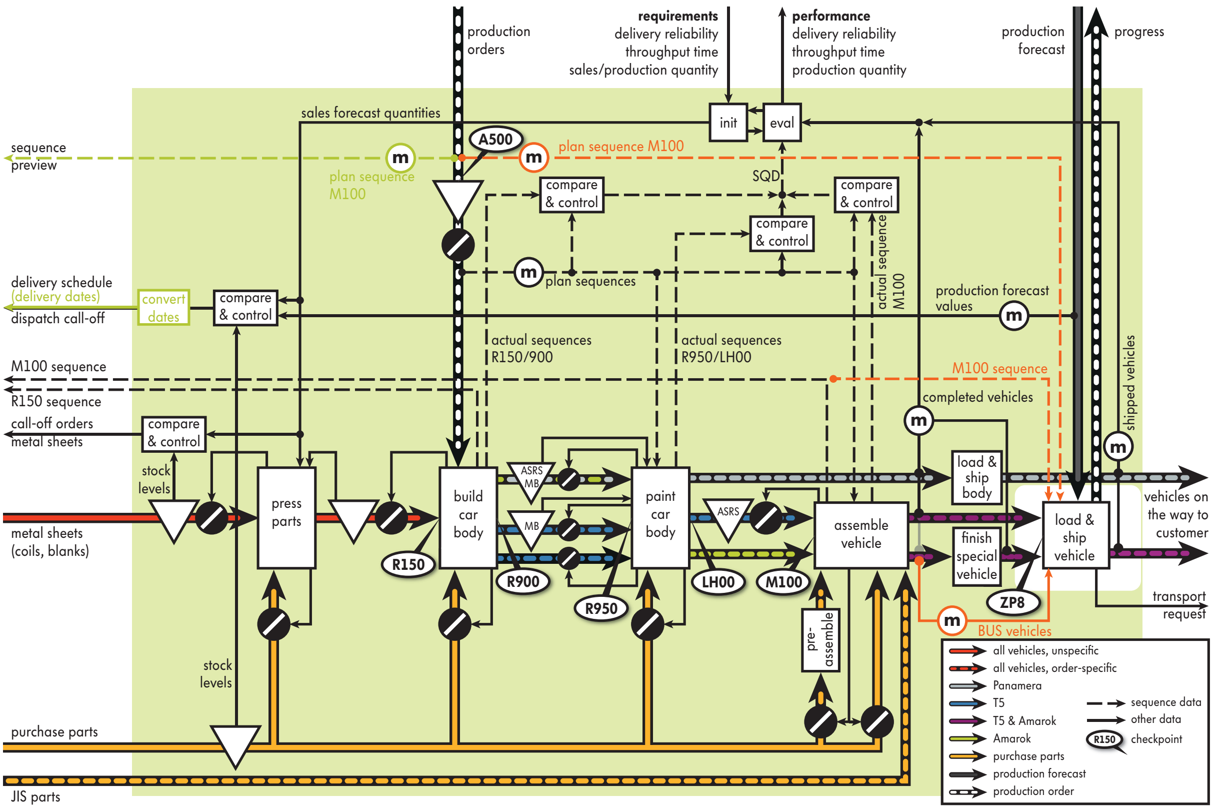

Figure 36: Proposed structural solution for improved process communication

Note that additional checkpoints for rework are not included in the figure, but should be implemented for rework stations of the three sections of body construction, painting, and assembly. Moreover, for implementation of the integration of scheduling and sequencing, there are additional changes required. These will be shown in the new model of the handle customer order transformation function in section 5.2.3.

5.2.1. Information and Coaching of JIS Suppliers

Rather than providing the expected shipping dates for their materials and components, suppliers of JIS components receive delivery schedules from which they derive the target completion dates of vehicles themselves. Additionally, JIS suppliers also receive a sequence preview six days prior to assembly, the actual sequence in body construction, and the final JIS call-off order. However, at least some of the suppliers are unaware of the use and accuracy of these datasets, and the specification sheet for JIS supply does not provide an adequate amount of information for a sound understanding of the matter. The approach for mitigation is illustrated schematically in Figure 37.

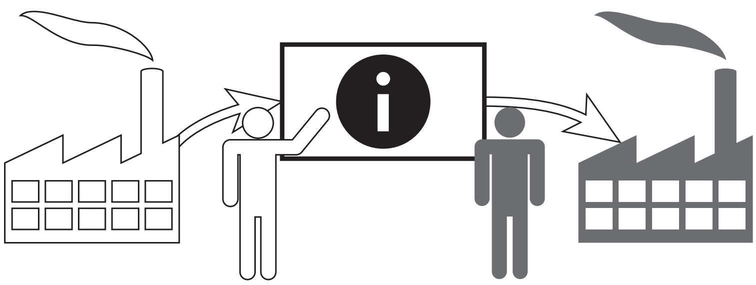

Figure 37: Information and coaching of JIS suppliers

Suppliers need more relevant and accurate information to plan their production. These suppliers are then able to reduce stocks, shorten cycle times, and improve economically – an improvement that can lead to mutually improved efficiency and effectiveness. Within the course of implementation of the new logistics concept some purchase parts suppliers receive shipping dates of their shipments rather than delivery dates (see section 2.4.4). This practice of transferring more relevant information should be translated to JIS suppliers by providing expected assembly or shipping dates rather than the vehicle identification number from which they derive the vehicles' completion dates.

Moreover, when the sequence preview is issued six days prior to assembly, the plan sequence transferred is that for body construction. Though there are only relatively small differences between the plan sequences for the T5[39] in body construction, painting, and assembly, the assembly sequence is the only sequence relevant to JIS suppliers. More importantly, if the radius for JIS supply were increased, suppliers could not use the sequences transferred at A500 or R150, as the plan sequence for assembly is restored in the ASRS. Therefore, the transfer of the assembly sequence at A500 provides a much more accurate data pool for suppliers.

Table 6 provides an overview of the differences between currently exchanged information and required information for the JIS suppliers for the T5. Discrepancies between current and desired state are highlighted in green. Note that for the Amarok suppliers receive the delivery forecast for up to nine months and a day schedule for completion for up to 8 weeks. In addition to the new data provided on a regular basis, relevant information on blocking of multiple vehicles should also be communicated to JIS suppliers in case of severe process disturbances. This helps to reduce the negative effects of internal process disturbances on the logistics process between suppliers and Volkswagen.

Table 6: Exchange of information between Volkswagen Commercial Vehicles and JIS suppliers

	current		required	
time to vehicle assembly	exchanged information	content	exchanged information	content
6 months to 3 weeks	delivery forecast	market-oriented forecast (±15%)	delivery forecast	market-oriented forecast (±15%)
3 weeks	day schedule for completion	VIN week block, vehicle completion dates	day schedule for assembly	VIN week block, vehicle assembly dates
6 days	planned sequence for R150 at A500	VIN day block in plan-sequence of body construction	planned sequence for M100 at A500	VIN day block in plan-sequence of assembly
2 days	actual sequence at R150	VIN in sequence of body construction	actual sequence at R150	VIN in sequence of body construction (for WIP syncing only)
0 day	actual sequence at M100	dispatch call-off per VIN, sequence number	actual sequence at M100	dispatch call-off per VIN, sequence number

Since the provision of accurate information to suppliers does not automatically improve their planning and scheduling, the qualification of suppliers is another, supplemental proposed method for improvement. Initially, suppliers' logistics and production departments have to understand what information has which accuracy and how changes in the production schedule of Volkswagen affect the different datasets. Together with the logistics department of Volkswagen the suppliers' planning and scheduling methods should be discussed, evaluated, and ultimately improved.

[39] for the Amarok the plan sequences in the different sections are identical

In addition, suppliers' turnover of personnel, especially of heads of the logistics and production departments, oftentimes results in a loss of knowledge about the different customer-supplier-relationships. For this reason, Volkswagen should offer coaching and brush up knowledge in workshops for suppliers on a regular basis. In addition to these workshops, suppliers should also receive up-to-date information about the relevant logistics processes at Volkswagen, such as the planning and scheduling steps and the corresponding datasets, which are sent to the supplier. This information needs to be plain and simple, contain graphs and figures about the relations between the different data, and an adequate level of detail.

In summary, JIS suppliers need to receive data relevant for the supply of their components. This includes not only target shipping data rather than target completion data, but also the planned assembly sequence rather than the planned body construction sequence. More importantly, coaching workshops shall be used to both clarify the information content of transferred data and optimize the supply process jointly.

Expectations and Key Performance Indicators for Assessment

The improved data quality and the qualification of both logistics and production departments of suppliers are expected to improve and stabilize the logistics processes. Improvement and stabilization of the processes includes the reduction of costs for parts, and most importantly an increased security of supply. The transfer of more relevant information to suppliers along with the qualification will improve the planning and scheduling processes at the suppliers and is likely to result in an increased productivity of the suppliers due to less exception handling.

As mentioned, the more demand-driven production results in an **increased security of supply**, since only the parts actually required on a short term are produced. Moreover, the improved planning also results in **lower inventory levels** due to the **ability to reduce safety stocks**, which will reduce the capital employed. Note that usually the capital employment is at cost of the suppliers, as the parts are only officially property of Volkswagen two line cycles after installation. These costs are, however, paid for by Volkswagen in different cost allocations. In addition to the capital employed, the auxiliary procurement costs may also be reduced in terms of costs for storage and handling as a result of the lower inventory levels.

The coaching of suppliers, however, also results in increased efforts in the logistics department due to the personnel required to qualify suppliers. Assuming that suppliers are offered one workshop every two years and that this workshop is held on one day by one delegate from the logistics department, the annual costs per supplier are roughly €750 to €1,000. Potentially these costs can even be passed on to the respective suppliers to mitigate the negative impact for Volkswagen, especially in cases where suppliers request the workshops.

For assessment of the measures, a number of performance indicators should be monitored. In the case of the security of supply, the **frequency of exception handling** should be monitored, which includes the frequency and severity of stock levels below safety stock level. For inventory reduction the **average stock levels per part**, both at the supplier and at the 3PL can be investigated, while the **costs for storage and handling** provide another indicator for improvement.

The **costs for parts** are a performance indicator that are results of negotiations with suppliers, but the increased effort for qualifications of suppliers and the resulting productivity are very likely to have a positive impact on negotiations. Lastly, efforts for the coaching of suppliers should be monitored using the **frequency of workshops** for suppliers and the corresponding costs.

Concluding, one can expect to diminish the identified problems in the problem category information of JIS suppliers. In the following section these measures will be validated and assessed.

Validation and Assessment

For external validation and assessment of the information and coaching of suppliers the head of production of JIS component supplier FICOSA International was interviewed. Internally employees of the logistics department of Volkswagen Commercial Vehicles were asked to validate the proposed solution. Figure 38 shows the previously discussed expectations and the experts' assessment of the solution with regard to the goals for assessment and the additional ones of costs for parts and security of supply. Note that the assessment in this case is limited to the area affected by the proposal.

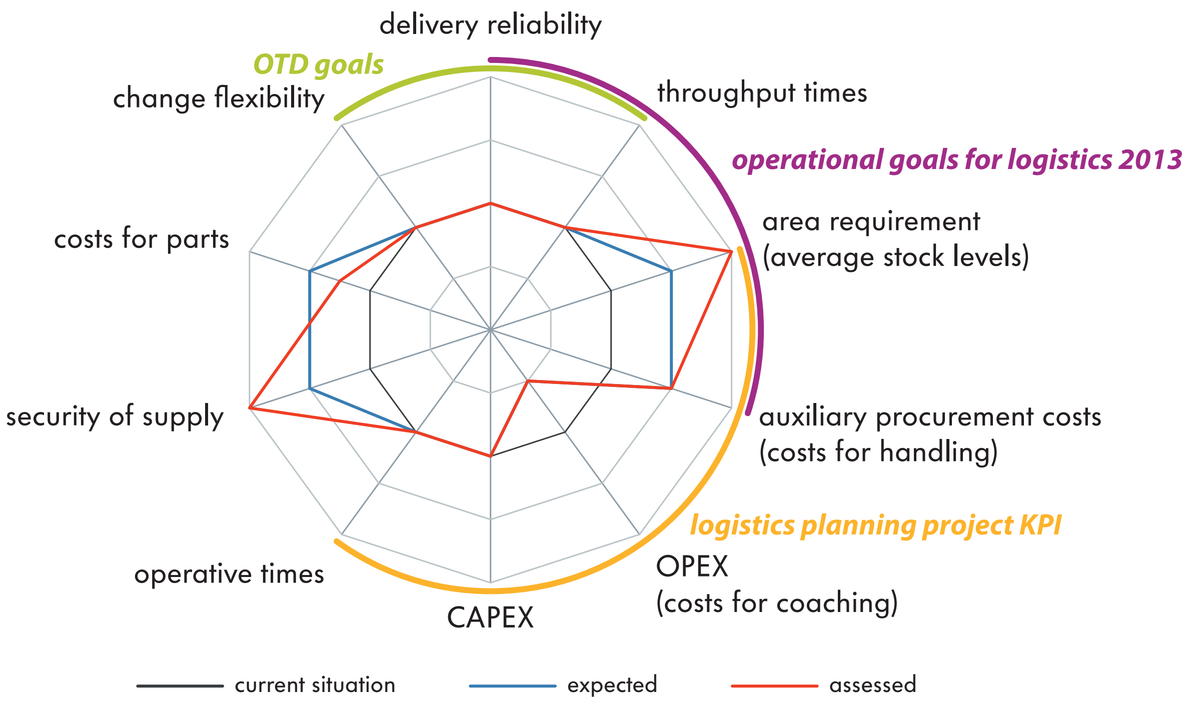

Figure 38: Spider chart for the information and coaching of suppliers

The spider chart shows that the results expected by the author and the results assessed by the experts are equal for most goals. While similar, there are still some differences between the results with regard to the security of supply, average stock levels, and costs for parts.

According to the experts from the logistics department of Volkswagen and the supplier FICOSA International, the security of supply can be increased severely due to the increased certainty of planning. This certainty results from the different datasets used for scheduling of the supplier's production, which provides data for parts needed within a few days rather than multiple weeks. While larger delays of demands are possible, the probability of very early demands – earlier than the safety stock time – for the specific parts is rather low.

Unfortunately, the unavailability of data with regard to KPI for measurement of the security of supply makes it impossible to assess this improvement quantitatively. Since the solution is deemed valid by all of the different parties without limitations, there is no further need to investigate its feasibility and it is assumed to be valid from here on. However, since the experts' qualitative validation provides a positive outlook, quantitative assessment will be used to investigate the solution in more detail.

In the case of rear view mirrors from FICOSA International, the three to 3.5 days safety stock with a value of roughly €1 million[40] may potentially be reduced significantly, which provides for the extensive potential with regard to capital employed and area required. However, capital employed is to the expense of Volkswagen, in this special case only. Safety stocks for other parts may also be reduced and thus the total area requirements may be reduced.

Currently the standard safety stocks[41] for German indirect JIS suppliers further away than 90km is 3 days. As mentioned earlier, however, some sequence deviations can be restored in the ASRS between the end of painting and the beginning of assembly. Since T5 are earlier than 310 sequence positions at LH00 in less than 0.1% of the cases[42], one can use this as a threshold for advance production of roughly two-thirds of a day to reduce the safety stocks. Using a safety factor of 2 or 3, the standard safety stocks reduce from 3 days to 1.03 or 1.55 days, respectively.

This means, that for these JIS suppliers the stock volumes can be reduced drastically. In the scenarios with safety factors of 2 or 3, the total stock volume at the 3PL for all T5 JIS components together decreases by 20.6% or 27.9% from 3895.5 m^3 [19] to 3093.7 m^3 or 2807.9 m^3, respectively. Table 7 shows the reductions for the German indirect JIS suppliers further away than 90 km[43]. The costs corresponding to the reduction of area requirements at 12.50 €/m^3 sum up to about €10,000 and €13,600 per year. This approach can also be used for both local and international JIS suppliers, as well as JIS suppliers for the Amarok, to reduce the stocks even further. Futhermore, the area that is made available by stock reductions can be used to purchase other parts as JIS components and thus reduce the costs for these parts.

Considering one workshop per supplier every other year at €2,000, the costs for the implementation in this scenario – for the 9 German indirect JIS suppliers, at least 90km off – is estimated at €9,000 per year. Consequently, the annual balance remains positive, between €1,000 and €4,600.

Moreover, the expected rise in costs for parts due to later production of the parts and thus the reduced ability for suppliers to optimize their production schedule will be marginal according to the experts' opinion. There may be some reductions in productivity and thus an increase in costs per part. For the example of FICOSA, however, the capital employed reduces by about €11,000 to €16,000[44]. Accordingly, the proposed solution is expected to provide savings in total. Even more so, it provides a method to extend JIS supply concept to other suppliers and components and thus reduce additional costs, as well as area in the purchase parts stock.

[40] For the T5 and Amarok combined.

[41] The current standard safety stocks for JIS suppliers within Germany are 1.5 days and 3 days for distances < 90 km and >= 90 km, respectively [20].

[42] In the period from 04-03-2013 to 19-04-2013 only 15 of 15687 T5 had a SQD < -310 positions.

[43] A more detailed table can be found in Appendix H.

[44] At a stock reduction of 48% to 65%, and assuming €800,000 stock value and 3% interest rate.

Table 7: Calculations of stock reductions for indirect JIS suppliers for the T5[45]

ID	country	distance to Hannover [km]	volume per day [m^3]	volume at 3PL, current [m^3]	volume at 3PL, reduced [m^3] safety factor 3	volume at 3PL, reduced [m^3] safety factor 2
1	GER	51	328	492.0	492.0	492.0
2	GER	55	14	21.0	21.0	21.0
3	GER	70	105	157.5	157.5	157.5
4	GER	85	13	19.5	19.5	19.5
5	**GER**	**90**	**9**	**27.0**	**14.0**	**9.3**
6	**GER**	**90**	**70**	**210.0**	**108.5**	**72.3**
7	**GER**	**145**	**147**	**441.0**	**227.9**	**151.9**
8	**GER**	**150**	**23**	**69.0**	**35.7**	**23.8**
9	**GER**	**160**	**57**	**171.0**	**88.4**	**58.9**
10	**GER**	**160**	**37**	**111.0**	**57.4**	**38.2**
11	**GER**	**180**	**22**	**66.0**	**34.1**	**22.7**
12	**GER**	**200**	**111**	**333.0**	**172.1**	**114.7**
13	DEN	450	22	110.0	110.0	110.0
14	CZE	480	2	10.0	10.0	10.0
15	**GER**	**690**	**77**	**231.0**	**119.4**	**79.6**
16	SVK	830	177	1416.0	1416.0	1416.0
17	ESP	2050	7	10.5	10.5	10.5
total [m^3]				3895.5	3093.7	2807.9
difference [m^3]					-801.9	-1087.6
difference [%]					-20.6%	-27.9%
savings [€]				12.50 [€/m^3]	-€ 10023.13	-€ 13594.58

Consequently, the information and coaching of suppliers is a valid method for improvement of the identified problems with regard to the information of suppliers and – according to both author and experts – will make the logistic processes more stable and efficient.

5.2.2. Additional Data for the Distribution Department

With regard to internal information, there is quite some potential in the reorganization of the communication structure. As the distribution department only receives preview data four weeks prior to vehicle completion, the accuracy of this data is rather limited. Therefore additional information has to be provided to support the planning of vehicle shipments. Short-term data is of special importance, as faulty planning causes problems in the distribution process.

For a thorough planning, it is important for distribution to receive detailed data on the vehicle that is relevant for shipping, such as the VIN, the destination region, the dimensions, weight, and whether or not the vehicle will receive treatment in the BUS. The information should be transferred timely, for example at the sequencing CP A500, and supplemented by additional sequence data.

Moreover, additional information on the actual sequence should be provided at R150 and M100, as the certainty of vehicles being ready for shipping on time increases as the vehicles move closer to completion. For this matter, the actual sequences of vehicle identification numbers should be provided to the distribution department.

[45] Data based on Volkswagen Nutzfahrzeuge [19].

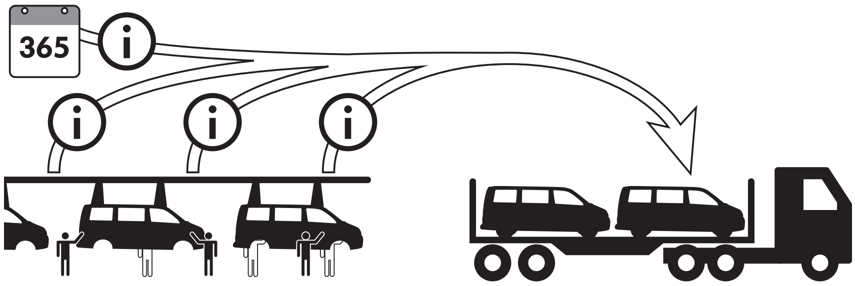

Figure 39: Provision of additional data to the distribution department

Figure 39 illustrates this concept and Table 8 summarizes both the currently provided information and the required information for the distribution department. The discrepancies between current and desired state are highlighted in red.

Table 8: Exchange of information with the distribution department

	current		required	
time to vehicle completion	exchanged information	content	required information	required content
4 weeks	ZP8 day schedule	daily completion volume	ZP8 day schedule	daily completion volume
8 days			planned sequence (A500)	planned sequence of completion: VIN, dimensions, weight, destination, BUS treatment
4 days			actual sequence (R150)	VIN in sequence
2 days			actual sequence (M100)	VIN in sequence
completion	completion notice (ZP8)	VIN, dimensions, weight, destination	completion notice (ZP8)	VIN, BUS treatment

In addition to the actual sequence data, distribution also requires information about vehicles in rework. This includes a notification whenever vehicles are sorted out along the production flow with an estimated time for reworking, as well as a notification whenever vehicles reenter the regular production flow. Another proposed CP is one that clearly marks all vehicles ready for shipping, as some T5 getting ZP8 status still have to be treated in the BUS.

In summary, the distribution department shall receive more information than it currently does. Up-to-date sequence data in production shall be transferred, along with information on vehicles that leave the regular production flow temporarily. Based on this new data the shipping of vehicles by truck shall be planned prior to vehicle completion, rather than waiting until all vehicles are actually available.

Expectations and Key Performance Indicators for Assessment

With regard to internal information, the proposed change of both the amounts and the quality of information for the distribution department are expected to have positive effects almost exclusively. The new information increases the ability to plan ahead and thus helps to reduce preparation times for freight forwarders. They can be booked for transport before vehicle completion rather than after vehicle completion, as there is more information available on which vehicles will be completed on a short term. This way the **inventory times** and thus also the **inventory levels can be decreased**.

Moreover, the larger information content provides a basis for **reduced shipping costs**, as one can predict much better when certain vehicles are completed and are thus ready for shipping. In addition to these costs, **OTD penalties are reduced**. These monetary penalties are issued for extended throughput times and can now be allocated using a cost-by-cause principle for vehicles that are in the BUS with the new CP. That is, the distribution department will not be charged for throughput times of vehicles in the BUS anymore. Unfortunately, IT systems and processes have to be altered for the newly transmitted information, which leads to **capital investments**. These investments, however, should not be very large, as the data is available in the system and only has to be transferred to the corresponding stakeholders.

On the one hand, KPI for aforementioned improvements are the **average inventory times** and **average inventory levels**. On the other, the different costs can be monitored using the **average shipping costs per vehicle**, the **average OTD costs per vehicle**, and the **total costs for the system setup** in terms of an offer or a bill, if implemented.

All in all, the proposed improvements are expected to solve the internal information problems. Though costs are required for the implementation of this concept, the expected benefits outweigh the expected efforts. In the following section, this set of measures for improvement is validated by an expert of the matter and assessed quantitatively.

Validation and Assessment

The expert for validation of the provision of additional data to the distribution department is the department head. From his point of view there is no significant downside to the implementation of the proposal. For provision of the data to freight forwarders, however, Volkswagen has to play openhanded. This means that the data on the sequence has to be transferred to the freight forwarders in order to allow for the optimized planning. Subsequently, freight forwarders are also able to get a glance at the deficiencies in the sequence. Nevertheless the solution is valid once the decision to share this information with freight forwarders is taken.

Beyond that the expert's assessment shows improvement of the current situation with regard to most of the goals. While the overall improvement is not quite as good as expected, there are only marginal negative effects of the implementation. As Figure 40 shows, the auxiliary procurement costs, operative times, and change flexibility remain unaffected by the proposal. Unfortunately, this is also the case for the external delivery reliability – contrary to the expectation. With the current sequence performance and adherence to production schedules, the expected improvement of delivery reliability cannot be accomplished.

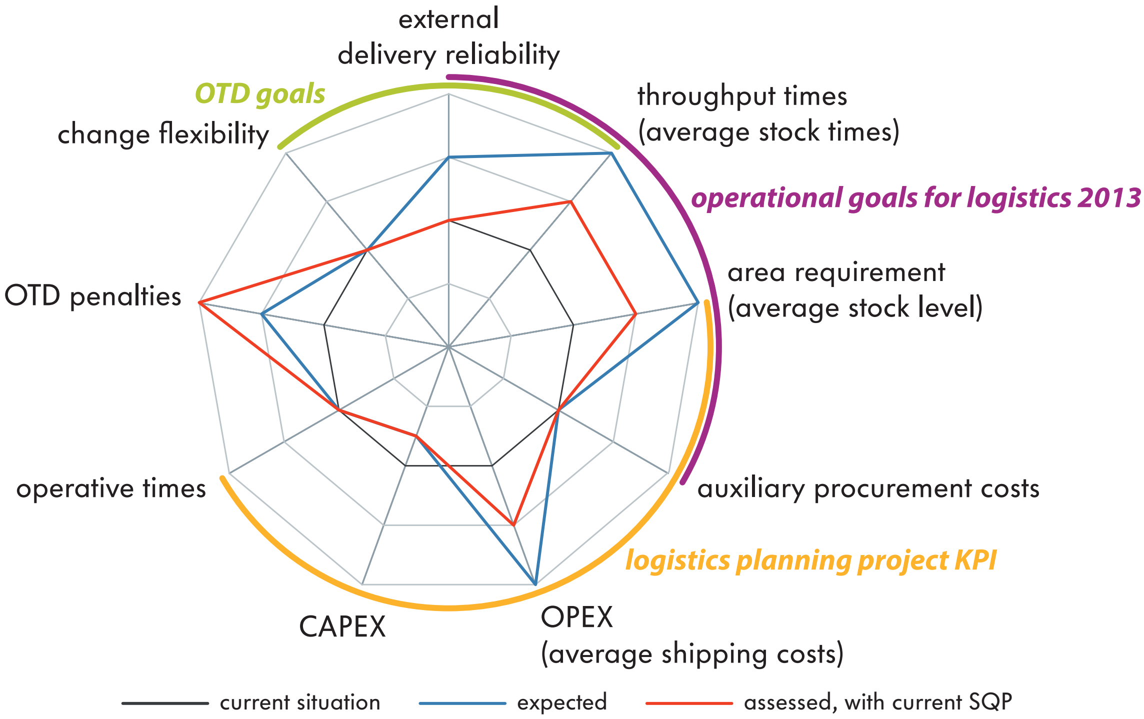

Figure 40: Spider chart for the provision of additional data to distribution department

The share of vehicles being distributed using vehicle transporter trucks is somewhat smaller than for trains, with about 44% for both T5 and Amarok. Distribution by train accounts for 50%, while 6% of the customers pick up their vehicles themselves. For 600 T5 and 120 Amarok being produced per day the current average inventory time for vehicles distributed by train and truck is 0.8 days and 2.19 days, respectively. Now let the reduced average inventory time be 1.5 days. The resulting average stock level for all vehicles reduces significantly by 22.3% from 982 to 763 vehicles. Table 9 lists the calculations for three scenarios with reductions of inventory times for vehicles shipped by truck to 1, 1.5, and 2 days.

Table 9: Calculations for the reduction of inventory in distribution

	model	vehicles per day	train [%]	truck [%]	inventory time train [d]	inventory time truck [d]	inventory combined, current [vehicles]	inventory time truck, reduced [d]	inventory combined, reduced [vehicles]	difference [vehicles]	difference [%]
scenario 1	T5	600	50%	44%	0.8	2.19	818	1	504	314	-38.4%
	Amarok	120	50%	44%	0.8	2.19	164	1	101	63	-38.4%
	total	**720**	**50%**	**50%**	**0.8**	**2.19**	**982**	**1**	**605**	**377**	**-38.4%**
scenario 2	T5	600	50%	44%	0.8	2.19	818	1.5	636	182	-22.3%
	Amarok	120	50%	44%	0.8	2.19	164	1.5	127	36	-22.3%
	total	**720**	**50%**	**50%**	**0.8**	**2.19**	**982**	**1.5**	**763**	**219**	**-22.3%**
scenario 3	T5	600	50%	44%	0.8	2.19	818	2	768	50	-6.1%
	Amarok	120	50%	44%	0.8	2.19	164	2	154	10	-6.1%
	total	**720**	**50%**	**50%**	**0.8**	**2.19**	**982**	**2**	**922**	**60**	**-6.1%**

While their respective throughput times and area requirements can be reduced significantly, the overall improvements are more subtle. The same also applies for the operational expenditures, which will be reduced for vehicles being shipped on the road, while rail shipping is improved only marginally, if at all.

OTD penalties, however, will be decreased drastically if the proposal is implemented. Vehicles' throughput times are only counted once they are ready for shipping and vehicles with the same destination can be predicted more accurately, and thus the cases in which it seems economically reasonable to delay vehicle shipping and accept OTD penalties – but turns out not to be – can be reduced severely.

The efforts for changes of the IT to provide the data to the distribution department are expected to lie around €12,900, as Table 10 shows. To take inaccuracies in the calculations into account, a safety factor of 1.5 is used. The reductions in area requirement of approximately[46] 2738m^2 correspond to about €13,700 per year[47] and outweigh the investments required. Consequently, the payback period for these two factors is approximately one year.

Table 10: Calculations for the required investments in the distribution department

post	item	IT	other
additional checkpoint infrastructure	effort [man-hours]	20	5
	hardware	€ -	€ 1000.00
	costs [€/h] [48]	€ 117.00	€ 117.00
	safety factor	1.5	1.5
	subtotal	€ 3510.00	€ 2377.50
data transfer to distribution department	effort [man-hours]	16	0
	hardware	€ -	€ -
	costs [€/h]	€ 117.00	€ 117.00
	safety factor	1.5	1.5
	subtotal	€ 2808.00	€ -
data transfer to freight forwarders	effort [man-hours]	24	0
	hardware	€ -	€ -
	costs [€/h]	€ 117.00	€ 117.00
	safety factor	1.5	1.5
	subtotal	€ 4212.00	€ -
	subtotal	**€ 10530**	**€ 2378**
		total	**€ 12908**

[46] At 2.5m by 5m per parking spot and 219 vehicles less with a reduced inventory time of 1.5 days, the reduction in area requirement is 2737.5m^2.

[47] At €5 per m^2 per year.

[48] Personnel costs of €117.00 result from an hourly gross wage of €90.00 and 30% payroll fringe costs.

Another cost factor in distribution, however, is exception handling. If the vehicles planned for shipping are not completed on time and there is no candidate to move-up for the same destination, exception handling is required. This means, that either the vehicle transporter waits for the vehicle to be finished, or the vehicle has to be sent on with another vehicle transporter. Both are costly options, and in the second case the first truck is underutilized, while the second may have to be requested for a single vehicle only. To estimate the impairment in utilization in shipping and thus the profitability, a simulation using current statistical data should be used.

Irrespective of the costs, however, the area itself is a valuable commodity. Due to the existing development around the plant site, there is no possibility of expansion to adjacent property. Imminent downsizing in area for parking for the construction of an additional pressing plant emphasizes how important it is to consider measures to reduce the area requirements in logistics.

In conclusion, the provision of additional data for the distribution department is a valid and positive method for improvement, which will help stabilize the processes while reducing costs. The problems with regard to internal information can thus be mitigated using these measures. Even more so, the imminent reductions in storage area for completed vehicles due to the construction of an additional sheet metal shop require reductions in area requirement, which supports the positive effect of the proposed solution.

5.2.3. Integration of Scheduling and Sequencing Functions

The problems with regard to scheduling and sequencing cannot be solved by different communication structures; and without structural changes in production the four identified problems' root causes cannot be treated. However, one can take the different throughput times in body construction and painting, as well as grouping for the wheelbase into account and thus treat the symptoms. While there is currently no grouping selection criterion set for the wheelbase in SONATA3, this is the easiest implementation of a problem solution.

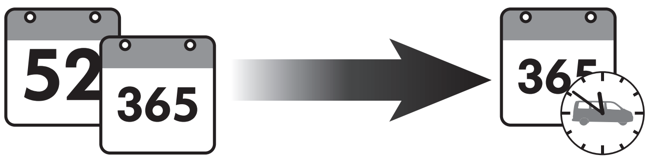

Figure 41: Integration of scheduling and sequencing

For this solution to take effect, however, the other problems have to be treated as well. As the illustration in Figure 41 implies that one option is to go from scheduling once a week and sequencing once a day to scheduling and sequencing in one step once a day, while integrating an appropriate sequence-shift for vehicles with longer throughput times. This step is described in more detail later in this section.

Figure 42 reveals that one way of achieving this is to integrate the scheduling and sequencing transformation functions into one new function. Subsequently, the requirements for the function have to be changed. That is, one has to change the selection criteria for SONATA3 and FIS DISPO II.

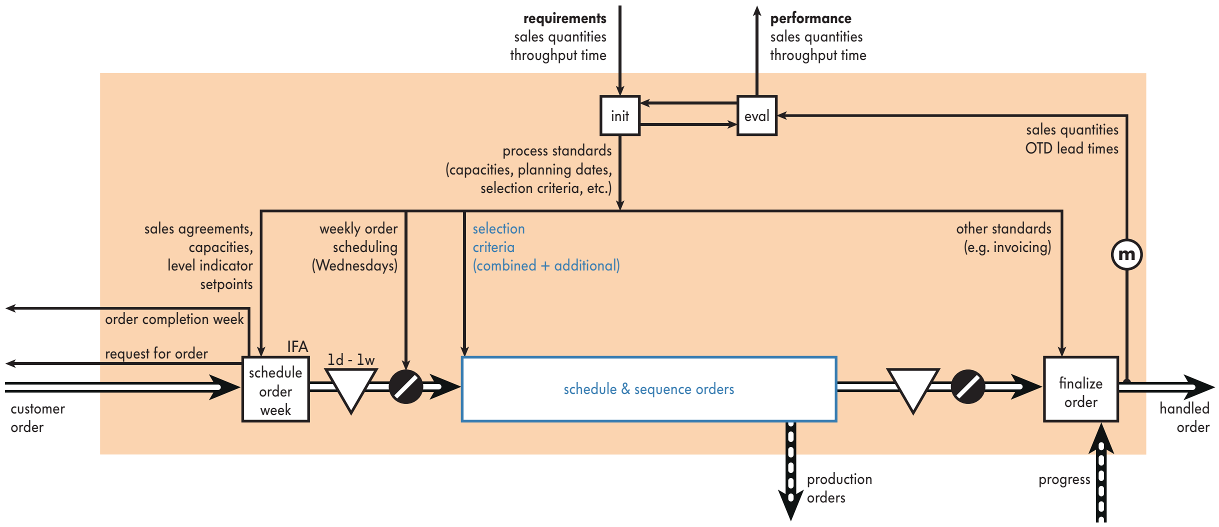

Figure 42: The newly integrated schedule & sequence transformation function

For the extended throughput times of DLP and NSR, as well as vehicles moving over PL 1, the new function has to include both scheduling and sequencing. The reason for the integration of the two previous functions into one is that the sequences for body construction and painting are currently determined only in sequencing with FIS DISPO II, but have to be determined iteratively in this scenario. Once this rolling wave sequencing is possible the vehicles can be assigned different extensions of the throughput time in the corresponding sections.

An example of the extended throughput times for T5 with a NSR, which are almost always delayed, can be seen in the boxplot in Figure 43, which was shown before in the problem definition. The figure shows the rough sequence deviation distribution per day at counting point R900, at the end of body construction. Median values in the figure suggest starting work on these vehicle bodies earlier by at least 50 positions prior to the initially planned beginning.

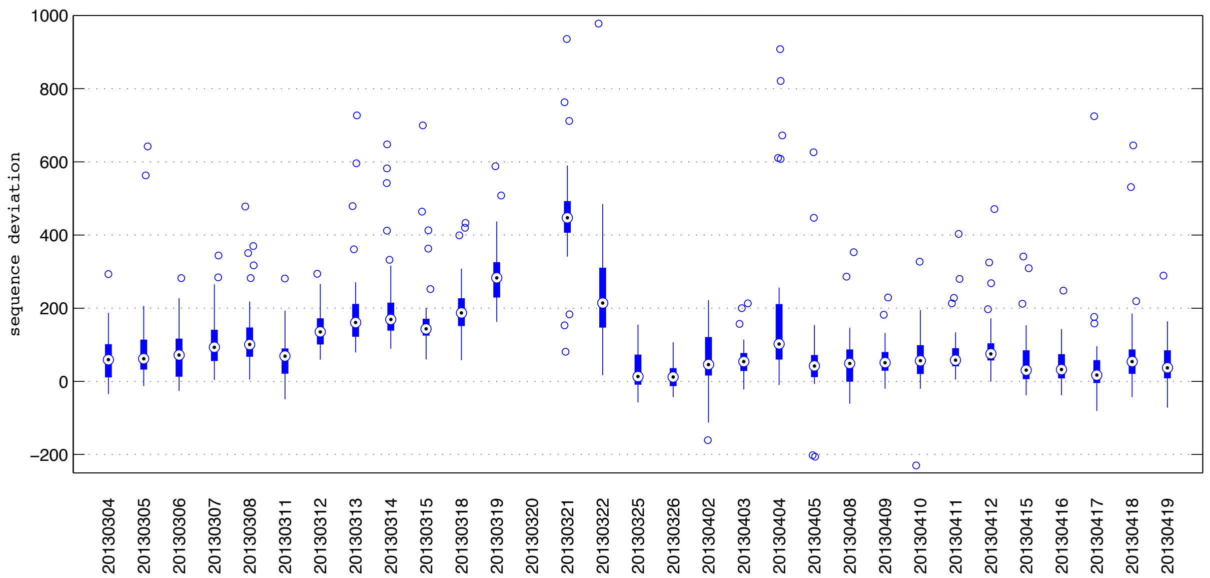

Figure 43: Boxplot of the sequence deviations for T5 with NSR at R900

The average median SQD for T5 with NSR is a delay of 97 sequence positions. In scheduling and sequencing, one could now shift the starting position in body construction for these vehicles forward by 97 positions, for example. The resulting new average median at zero[49] would be a great improvement over the current situation.

Though T5 with NSR account for an average of 8.5% for the given period, there are other features that were identified as problematic as well. For vehicles with DLP colors at LH00 after painting, or those that are processed on PL 1 at LH00, the boxplots (see Appendix H) suggest similar measures. Table 11 summarizes the most important data for the different analyses.

Table 11: SQD values for the three suggested features (T5 in the period 04-03-2013 – 19-04-2013)

feature	check-point	avg. min SQD	avg. median SQD	avg. max SQD	avg. vehicles per day	avg. percentage
T5 with NSR	R900	-27	97	836	45.4	8.5%
T5 with DLP	LH00	65	221	688	4.3	0.9%
T5 on PL1	LH00	64	291	1769	46.0	9.1%

Moving the beginning of work on a vehicle with longer throughput times to a previously sequenced day is impossible at this moment. This makes it impossible to shift orders to a different production day. Therefore the scheduling and sequencing has to be an integrated and iterative process that sets the assembly sequence first and subsequently sets the sequence for painting before setting the body construction sequence; all in a rolling wave planning.

If necessary, the start of body construction or painting for specific vehicles with longer throughput times has to be pulled to a day prior to the initially planned one. This way the prolonged throughput times have a much smaller impact on the sequence at the beginning of assembly, while still taking constraints in painting and body construction into account.

This iterative process may result in delays in data release, but the sequence is frozen just shortly after the point in time currently used for scheduling. Therefore the data's informative value can be increased and negative effects can be prevented. Even more so, the increased frozen period also provides a better basis for planning of numerous suppliers, and can thus indirectly improve both productivity and the security of supply.

Nevertheless, this new function has to be automated like the currently separate functions of scheduling on the one hand, and sequencing on the other. As in the current situation, the resulting sequences should still be manually checked and released if deemed satisfactory.

In summary, the integration of scheduling and sequencing implies the reduction of sequencing steps. In the determination of the sequence used to create day schedules, additional criteria shall be used to assure balanced workloads in assembly. Therefore this sequence can then also be used for assembly directly without an extra sequencing step. Moreover, those vehicles with NSR, DLP, or painted on PL 1 shall be shifted within the body construction and painting sequences to account for longer throughput times in body construction and painting.

[49] the actual average median will turn out higher due to shifts between the different orders

Expectations and Key Performance Indicators for Assessment

The newly integrated system for scheduling and sequencing with the new selection criteria and sequence-shifting is expected to have a positive effect on the sequence. By taking the longer throughput times for some models in the different sections into account, the output sequences of the sections will converge towards the plan sequence of the downstream process. Unfortunately the negative effects of process disturbances cannot be treated this way.

Nevertheless the large delays in body construction due to manual labor on different types of NSR, and the negligence of DLP in painting, as well as the increased throughput times of PL 1 can be reduced to a more reasonable level. Additionally, the lack of grouping for the wheelbase of the T5 in SONATA3 is irrelevant if schedule and sequence are identical. All in all, the changed scheduling and sequencing should **increase the sequence performance values** at the different sections. Additionally, an increased sequence performance also **decreases the average throughput times** for orders due to decreased average waiting times.

Moreover, automating the function should most likely **reduce the effort for scheduling and sequencing**. On the one hand the reduced effort results from the reduction of steps in sequencing. On the other hand it results from the reduced sequencing frequency from once a day to once a week. Moreover, suppliers can now be provided with the required material sequences at an earlier stage, which may increase their productivity and help improve and stabilize the logistic processes even further than proposed in section 5.2.1. Suppliers of purchase parts should also profit from the increased informative value of available data and be able to reduce the safety stock levels and thus **reduce the area requirement.**

Though the ability to change orders for the customers barely changes, there is still a negative effect. Currently it is possible to change only non-restrictive features of the vehicle. These non-restrictive features are thus extended by the added selection criteria, which does result in **slightly decreased change flexibility**. Another negative effect of the integration of the systems are **capital expenditures** required for the system and process reconfiguration.

For assessment of the expectations there are a number of performance indicators. While the sequence performance values at R150, R900, LH00, and M100 are concentrated key figures, it is more advisable to use the **sequence deviation diagrams** for CPs **R150-R900**, **R950-LH00**, and **A500-LH00** for improvement of body construction, painting, and the overall improvement of the sequence performance up to assembly, respectively.

Moreover, the **average throughput times** for orders can be measured to check whether or not they are indeed reduced through the improved sequence performance. Reduced area requirements can be assessed using the **stock levels for parts**, though safety stock levels had to be reduced as a result of more accurate data. For the reduced efforts in scheduling and sequencing **interviews with the systems' users** before and after introduction of the new system may be conducted to assess the time spent in checking and releasing the orders after the scheduling and sequencing runs. The capital expenditures are much easier to assess, as there will be an offer and subsequently a bill indicating the **total costs for the system setup**.

Validation and Assessment

For validation and assessment of this suggested method for improvement, an expert of the program planning department was interviewed. One of the results is that the sequence-shifting is indeed a valid one, according to the expert, as there are no criteria for exclusion violated. Moreover, scheduling and sequencing may indeed be integrated.

Changes in IT and processes, however, are more extensive than initially expected by the author. Not only the planning and scheduling process would have to be altered, but also the adjacent processes. These changes require significant capital investments with regard to IT and process, as can be seen in the spider chart in Figure 44. Nonetheless, the expert confirmed the validity of the solution despite these required changes, but stressed the severe changes necessary to integrate the functions of scheduling and sequencing.

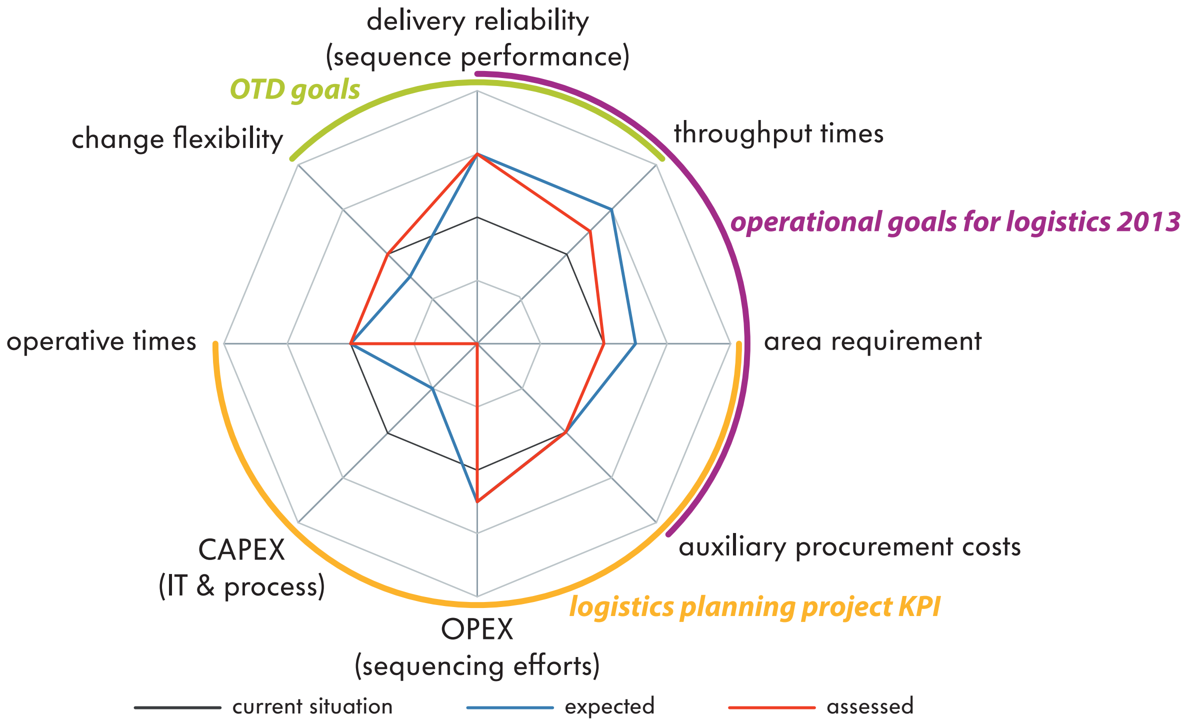

Figure 44: Spider chart for the integration of scheduling and sequencing

Although there were also negative impacts expected with regard to change flexibility, implementation does not affect the change flexibility in the expert's opinion. Another goal that is unaffected by the integration of scheduling and sequencing functions is the area requirement, as it is unlikely that the safety stock levels may indeed be reduced after implementation of this particular measure. Moreover, auxiliary procurement costs and operative times are not likely to be affected by this method, either.

Fortunately there are also some positive effects, according to the expert. The researcher's expectations and the expert's assessment match with regard to the delivery reliability, which will likely improve internally and subsequently also externally. Moreover, the reduced frequency of scheduling and sequencing steps reduces the work efforts required and thus slightly reduces operational expenditures. The throughput times may also improve, though most likely to a marginal degree only, because a reduction of the amount of vehicles in the different buffers between the production steps will presumably remain untouched.

Moreover, during assessment of the solution an issue with regard to the exchange of information came up: the release of data to suppliers. As the new process is iterative, the data cannot be sent to suppliers immediately, but only after the last iteration of the process. This way it is ensured that the data is correct and up-to-date.

Since the CAPEX are a very large downside to implementation of this solution the costs have to be estimated. This is done for each of the OTD's sub-processes and the results are illustrated in Table 12. The calculations show that the new system requires investments of more than €310,000 and annual maintenance of about €14,000.

Table 12: Estimated costs for implementation of the integration of scheduling and sequencing[50]

	post	sales	planning	supply	production	distribution	subtotals
CAPEX	detailed investigation on required changes	€ 2808	€ 24570	€ 9828	€ -	€ -	€ 37206
	preparation of implementation	€ 7020	€ 56160	€ 14040	€ -	€ -	€ 77220
	coaching (nonrecurring)	€ 10020	€ 2406	€ 35580	€ -	€ -	€ 48006
	implementation	€ 7020	€ 70200	€ 28080	€ -	€ -	€ 105300
	documentation	€ 8520	€ 17040	€ 17040	€ -	€ -	€ 42600
	subtotals	€ 35388	€ 170376	€ 104568	€ -	€ -	**€ 310332**
OPEX	maintenance p.a.	€ -	€ 7020	€ 7020	€ -	€ -	€ 14040
	subtotals p.a.	€ -	€ 7020	€ 7020	€ -	€ -	**€ 14040**

The expected reduction in sequencing efforts can also be determined. Assume that currently scheduling with SONATA3 requires one hour per week and sequencing with FIS DISPO II requires one hour per day. Combining the two in one system may require twice as much time in SONATA3, but no additional sequencing efforts in FIS DISPO II. The resulting efforts are thus six hours and two hours per week in the old and new situation, respectively. Table 13 shows the estimated annual costs for sequencing efforts. With just these savings of approximately €22,000 per year and the annual maintenance costs of €14,000, the payback period exceeds the company standard of two years by far.

Table 13: Estimated annual costs for sequencing efforts

situation	work effort per week [h]	production weeks per year	work effort per year [h]	costs [€/h]	Distribution
current	6	47	282	€ 117	€ 32994
integrated	2	47	94	€ 117	€ 10998
				Difference	**€ 21996**

Despite the extensive investments, some rough calculations are done to assess the utility of this measure. Per CP, all actual orders are given a sequence number s_i from 1 to n (number of all orders). Following this, a new position number n_i is calculated by subtracting the mean median SQD of 291, 221, or 91 from s_i for vehicles with DLP, PL 1, or NSR, respectively[51]. This new position number is then used to sort the orders, which are subsequently given a new sequence number sn_i from 1 to n.

[50] Appendix H includes a more detailed table.
[51] In case of vehicles with multiple of said features, only the highest of the values is subtracted.

Per order, the new sequence deviation $SQDn_i$ is now the initial SQD subtracted by the difference between the old and new sequence position numbers s_i and sn_i. This way there are no two orders with the same new sequence number and overlaps among the newly calculated positions are taken into consideration. In case the n_i for two orders are identical, the sn_i among these two is determined arbitrarily. Table 14 shows an excerpt of the table for the previously described calculations.

Table 14: Excerpt of the calculations for determination of new sequence deviation

color	PL	roof	sequence number s	new position number n	new sequence number sn	SQD	new SQD	production date	new production date
standard	4	standard	7231	7231	7283	-173	-121	20130322	20130322
standard	**1**	**standard**	**7523**	**7232**	**7284**	**113**	**-126**	**20130325**	**20130322**
standard	4	standard	7233	7233	7285	-114	-62	20130322	20130322
standard	4	standard	7234	7234	7286	-153	-101	20130322	20130322
standard	4	standard	7235	7235	7287	127	179	20130322	20130322
standard	**4**	**NSR**	**7332**	**7235**	**7288**	**633**	**589**	**20130325**	**20130325**
DLP	**4**	**standard**	**7456**	**7235**	**7289**	**11**	**-156**	**20130325**	**20130325**
standard	4	standard	7236	7236	7290	-191	-137	20130322	20130325
standard	4	standard	7237	7237	7291	-185	-131	20130322	20130325
standard	4	standard	7239	7239	7292	-138	-85	20130322	20130325

The calculations for LH00 show that shifting the start of production for T5 with NSR or DLP, or which are painted on PL 1 do in fact improve internal delivery reliability. Table 15 shows the key figure values of sequence performance, sequence window reliabilities, and the standard deviation around zero for the two different situations. A full table of key figures for each feature can be found in Appendix J.

Table 15: Key figures at LH00 before and after the introduction of sequence-shifting (T5 for the period of 04-03-2013 - 19-04-2013)

key figure	current situation	sequence-shift DLP/PL1/NSR	difference
SWR(0) = SQP	72.5%	73.7%	+ 1.2%
SWR(10)	73.4%	75.3%	+ 1.9%
SWR(400)	94.8%	96.1%	+ 1.3%
standard deviation	374	348	- 26

These values seem rather small with just 1.2%, 1.9%, and 1.3% for the SQP, SWR(10), and SWR(400), respectively. Nevertheless, the sequence deviation histogram in Figure 45 shows the improvement much better. It illustrates how the average mode shifts more towards the target value, from -120 to -90, while the average median shifts from -103 to -80. The cumulative lines also imply the improved standard deviation from 374 to 348. Thus, the sequence-shift performance is clearly better than in the current situation. Note that the full sequence deviation diagram can be found in Figure 76 in Appendix H.

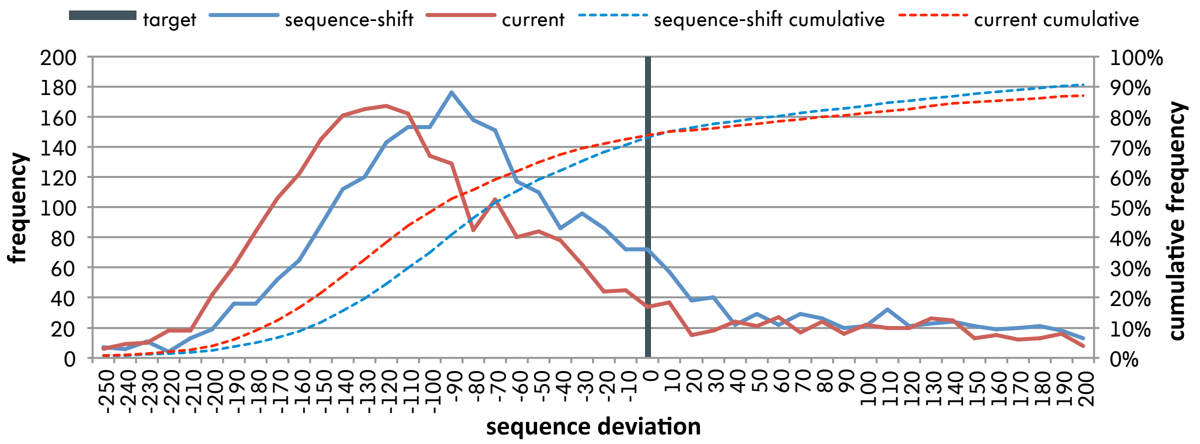

Figure 45: Partial sequence deviation histogram for T5 with sequence-shifting at LH00 for week 10-2013 (DLP = -221 | PL1 = -291 | NSR = -91)

The data shows that in the new scenario 90% of all vehicles are not more than 180 sequence positions late. Previously, this upper-90% mark was at a sequence deviation of 265. Moreover, 90% of all T5 are currently less than 185 positions early, while with sequence-shifting this lower-90% mark is reduced to 160.

Note, that in the calculations for LH00, there are only marginal improvements for vehicles with NSR. On the one hand the data for the end of body construction (R900) shows a reduced standard deviation from 187 to 181 and a shift of the median from -29 to -23. One the other, at LH00 sequence-shifting using only NSR vehicles results in shift of the median from -103 to -100 and a standard deviation of 372 instead of the previous 374. Consequently the results are significantly less positive at LH00. This may point to additional disturbances in the painting process caused by vehicles with NSR.

Additionally, the approximation calculation (1) by Inman [40] is used to assess the effects on the service level in assembly for a given number of cells in the ASRS dedicated to resorting of orders only. This approach ignores a certain number of elements[52] with the largest absolute SQD and calculates the number of dedicated resorting cells. These cells are needed in the ASRS to achieve the desired service level in a situation with entirely elective access to the orders available in the ASRS.

$$D(l) \approx 1 + |F^{-1}(x)| + \frac{\sum_{k \in S - S_r} d_k}{n_r} \tag{1}$$

where

$D(l)$	the most negative sequence displacement after ignoring y orders with the most negative sequence displacement in the original population,
l	the in-sequence service level in percentage terms,
$F^{-1}()$	the inverse cumulative distribution function of raw sequence displacements,
d_k	the sequence displacement of order k in the sample after y orders have been ignored,
S	the set of orders in the original sample,
S_r	the set of orders remaining after ignoring y orders,
n_r	the number of orders in set S_r,
y	the number of orders ignored, $n^*(1-l)$

[52] Corresponding to the service level. For l=95% and n=1000, y=1000*(1-.95) = 50 orders are ignored.

The analysis shows a significant increase in the theoretically possible service level with an equal number of cells, as illustrated in Figure 46. For the investigated service levels between 48 and 61 cells less are required for the situation with sequence-shifting than in the situation without sequence-shifting. For example, with 289 resorting cells in the ASRS a service level of 85% can be achieved with the current sequence deviations. With sequence-shifting, 286 resorting cells provide a service level of 95%. A detailed table of the data is provided in Appendix J.

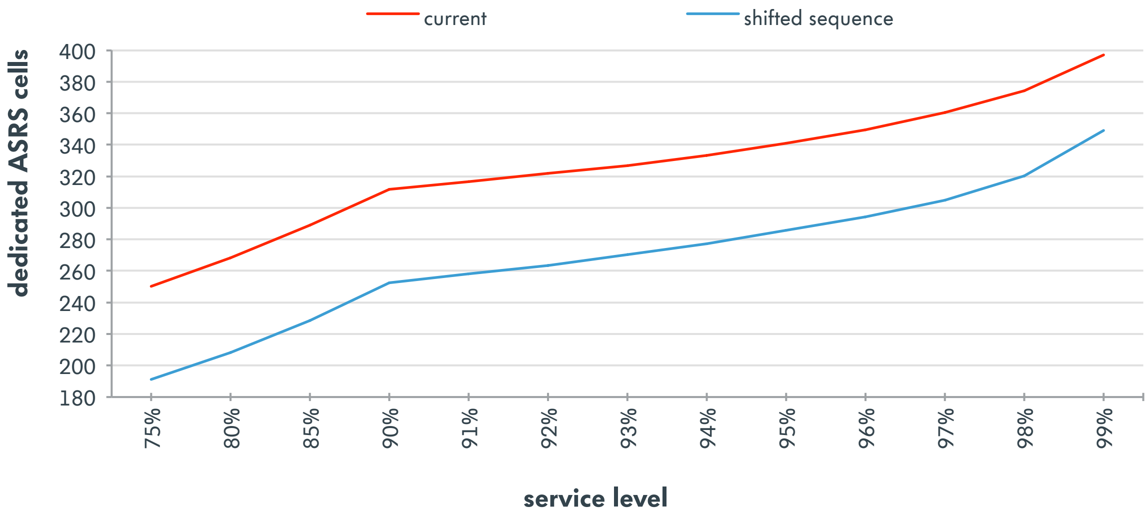

Figure 46: Number of required ASRS cells for resorting as a function of service level in assembly

Regardless, changes of the ASRS are currently not up for debate and the service level in itself does not provide direct cost savings. Nevertheless, a high service level in assembly is essential for the possible implementation of a long-distance JIS process, as the service level determines the number of components that have to be resorted to match the actual vehicle sequence.

However, although there are certainly positive developments on the delivery reliability and service level, it is hard to estimate the profitability of this measure for the current situation. Except for the reduced costs for sequencing efforts in planning and the difficult-to-estimate gains in utilization in assembly, there are no direct savings. Notably, a 90% adherence to the day schedule at the beginning of assembly is one of the operational goals for logistics in the 2nd half of 2013, which is supported by sequence-shifting.

Another problem that may arise is the limited predictability about whether or not a vehicle should be painted on PL 1 rather than the other lines due to efficiency reasons. If prediction is impossible, sequence-shifting may also be introduced for vehicles with NSR or DLP only. A different approach for this problem is to schedule certain numbers of vehicles on PL 1 to reduce the overall delay and tolerate deviations for the remaining vehicles on PL 1.

In conclusion, sequence-shifting is a viable option that helps to reduce the impacts of the special vehicle body construction with regard to NSR, and the extended throughput times for vehicles with DLP and the throughput times of PL 1. Moreover, the integration of scheduling and sequencing solves the problem of the difference between the target and plan sequence. Due to the high costs, however, it is less likely to be implemented. A more elaborate investigation of additional feature-related delays in production may change this, but considered improbable in a magnitude necessary to make it profitable.

6. Improvement Concept Proposal

In chapter 5 three different approaches for improvement of the logistics of Volkswagen Commercial Vehicles in Hannover were introduced and discussed individually. The first two solutions of information and coaching of suppliers and the provision of additional information for distribution are considered to be profitable within their respective areas. The third solution, however, is not profitable in its direct environment.

Consequently, the improvement concept comprises the first two proposed solutions, as illustrated in Figure 47. These parts of the concept are:

- information and coaching of suppliers (see section 5.2.1)
- the provision of additional information for distribution (see section 5.2.2)

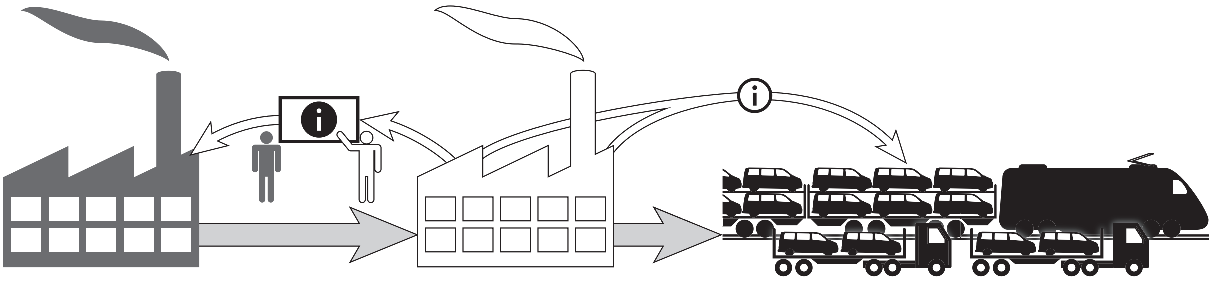

Figure 47: Final improvement concept schematic

In summary, the first of these two the JIS suppliers receive new data and are coached with regard to the logistics process. The data transferred to JIS suppliers shall be changed to the data relevant for suppliers. That is, they receive the planned assembly sequence rather than the planned body construction sequence, for example. When communicating with suppliers about this new data, one has to seize the opportunity to also coach the suppliers on the quality of information and make clear what different changes in the data have which corresponding effects. By also discussing and evaluating the planning and supply process of the suppliers with them, the processes can be improved and stabilized greatly. Hence, the security of supply will increase, and area requirements and auxiliary procurement costs will decrease, supporting the targeted cost reductions for the logistics of Volkswagen Commercial vehicles as described in section 2.3.

In the second part of the concept, Volkswagen should provide the additionally required information to the distribution department. This information includes the vehicle-specific shipping characteristics, sequence data, and data for tracking of vehicles that are taken out of the production flow (see section 5.2.3). The relevant information also has to be made available to freight-forwarders to benefit from the additional data and thus to reduce shipping costs, throughput times, and area requirements.

6.1. Discussion of the Concept

Section 5.2 described the validity of the two parts of the concept and pointed out the beneficial effects of the measures on the KPI and their respective profitability. Moreover, indirect effects of the integration of scheduling and sequencing with sequence-shifting on the other processes are expected in the supply and distribution process as a result of higher delivery reliability.

However, the 0.1% level of early production used for the estimation of effects on the safety stocks for JIS components is even earlier than initially[53], due to the sequence-shifting. This impoverished the stock reductions by 2% points if implemented, and is thus unfavorable. Additionally, the positive effects on the distribution process calculations in section 5.2.2 as a result of higher delivery reliability are negligible. Vehicles are expected to be in the inventory for 1.5 days, hence the reduced delays of 291 sequence positions, for example, have no effect on distribution. Therefore, the large capital expenditures and little direct and indirect cost savings do not justify the implementation of this measure. Though there is definitely a positive effect on the delivery reliability, these improvements cannot be linked to a strong increase in profitability required to bring the payback period to a reasonable level.

Nevertheless, if the delivery reliability up to the end of painting can be increased in such a way that the ASRS is able to restore the initially planned assembly sequence to a very high service level, then the JIS supply process profited greatly. A high service level of 90% is also set as one of the operational goals in logistics for 2013. One reason for this is that a high service level – well-above 90% – complied with the requirements for long-distance JIS supply; a practice expected to provide extensive cost savings with regard to the auxiliary procurement costs [21].

Additionally, high delivery reliability between the end of painting and completion helps to reduce the time between request for shipping by truck and the actual shipping. This reduction in inventory time for said vehicles helps to reduce the inventory even further and makes the proposal more profitable and the distribution process more efficient.

According to this outlook, the two proposed parts of the concept do not only provide process improvements for the current situation, but – provided the production-related process disturbances of the sequence are reduced – also provide a very good framework for further improvement in the future.

The following chapter focuses on the implementation of this final improvement concept and provides a preliminary implementation plan to ensure successful adoption of the proposed changes.

[53] 335 positions as opposed to 320.

7. Implementation

The beneficial effects of the final improvement concept are shown in section 5.2 and chapter 6. The following step is to make a decision on what to implement exactly and, consequently, the actual implementation of the changes themselves. The following sections provide an overview of what is required for decision-making and for leading and managing the change to ensure supple implementation.

7.1. Decision-Making

For decision-making on whether or not the proposed changes shall be implemented, it is important to include those responsible for the processes within Volkswagen. This means, that for the information and coaching of JIS suppliers and the provision of additional information of distribution the department heads of the supply, distribution, and logistics department and their superiors have to be included. This is necessary to have a broad support of the decision in these key areas.

A detailed utility and profitability analysis – supported by the quantitative assessment of the solutions in section 5.2 – is the most important factor for the decision. A well-founded decision in favor of the proposal is possible only once the analysis shows the economic feasibility and little risk of the concept in detail. After these studies are conducted and the decision is taken, change can actually be implemented.

7.2. Leading and Managing Change

For leading and managing change, the theory of organizational change by Cummings and Worley [41] is adapted to the scenario at hand. This theory includes five main factors to consider in the implementation plan. These factors are:

1. motivating change,
2. creating a vision,
3. developing political support,
4. managing the transition, and
5. sustaining momentum.

These factors are explained and applied to the situation at hand. However, since this is just a preliminary implementation plan to provide a basis for a detailed implementation plan, the level of detail is restricted to rather superficial analysis.

7.2.1. Motivating Change

Motivation for change is very important to create a certain readiness in stakeholders and to overcome resistance. The creation of readiness in this case can be achieved through stressing the need for change, such as the upcoming challenge for the T5 posed by Ford's new Tourneo, for example. To maintain the high market shares for the T5, it is important to have a good balance between delivery times, cost, and quality of the product. Discrepancies between current and desired cost and delivery times can be used to underline the need for change, and the positive impacts the proposal has on these factors can help to ensure everyone sees its benefits to the company's goals.

Outside of Volkswagen – towards the suppliers – the positive effects on the entire supply chain are communicated to spark the suppliers' interest in the proposal. Seeing that not only Volkswagen but also they benefit from the changes, the willingness to partake in the new process rises.

Communication on the proposal and its status changes and progress are also very important to raise empathy and support for the project and thus overcome resistance. Another way to overcome resistance is to involve the relevant stakeholders and let them participate in the progress actively. This is of special importance with regard to the JIS suppliers when it comes to the implementation of coaching workshops and the following changes within their planning and production processes.

7.2.2. Creating a Vision

The second factor of creating a vision seeks to describe the core ideology and construction of the envisioned future of the change. In general this step is focused on changes in company strategy, but since the proposal fits with Volkswagen's Strategy 2018, the vision is already created and has to be reinforced.

Towards suppliers, the more demand-appropriate supply process helps to create more stability and a beneficial factor that can provide a prospect for long-term collaboration.

7.2.3. Developing Political Support

Development of political support is an important part, as rejection of the change proposal by key stakeholders jeopardizes the successful implementation of the concept. In a first step a change agent has to be appointed. As the change agent is the main driving force behind the change, a sufficient amount of hierarchical power is required.

The next step is the identification of key stakeholders for the project. Among these are the department heads and their superiors, but also the affected JIS suppliers' CEOs and heads of production and logistics. Where necessary, these stakeholders shall be convinced of the positive effects of the proposal on the process relevant for the stakeholder.

7.2.4. Managing the Transition

Transition management implies the planning of how things are supposed to be changed over time. During change, the processes will each be in a transition state that is different from both current state and desired future state. This transition state can also be seen in the activity planning for change. An example of activity planning for the second solution with regard to vehicle distribution is illustrated in the process map in Figure 48.

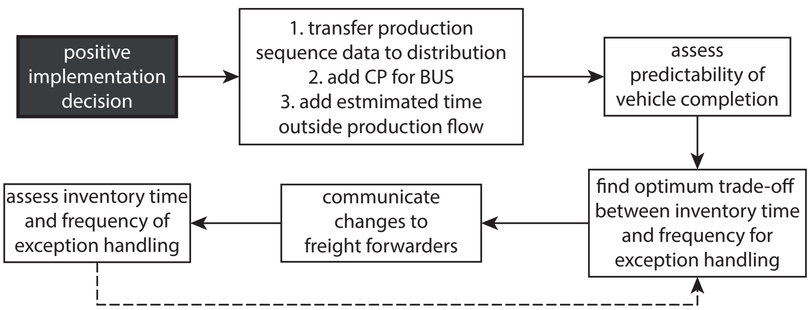

Figure 48: Process map for implementation of additional information for distribution

In the transition state the production sequence data is transferred to production, an additional CP for vehicles that receive special treatment is installed, and estimated times for vehicles outside the production flow are transferred to distribution. The assessment of the predictability of vehicle completion dates marks the end of the transition state.

Predictability of vehicle completion dates is important in order to determine the frequency for exception handling and the time that has to be between theoretical completion and actual shipping through freight forwarders. The sequence data corresponding to this time is consequently sent so freight forwarders as a shipping request.

To make sure the effects on the process are positive, the inventory times and frequency of exception handling for delayed vehicles are assessed and provide a basis for optimizing the trade-off among the two. The actual ratio of these values depends on the financial merits assigned to a reduction of the lead time compared to the difference of costs for exception handling and savings for area reductions. The optimization itself is an iterative process, since changes in the production process may occur and the initially assessed predictability of vehicle completion may become inaccurate. After the first iteration the desired future state is achieved, and the process data is optimized periodically.

The process map for the solution regarding JIS suppliers is more complex, as shown in Figure 49. The transition here is everything until the rollout of the new process is over. Ideally, one JIS supplier can be involved to test the concept. This supplier shall be willing to share the risk of the process change and have abundant stock at the 3PL.

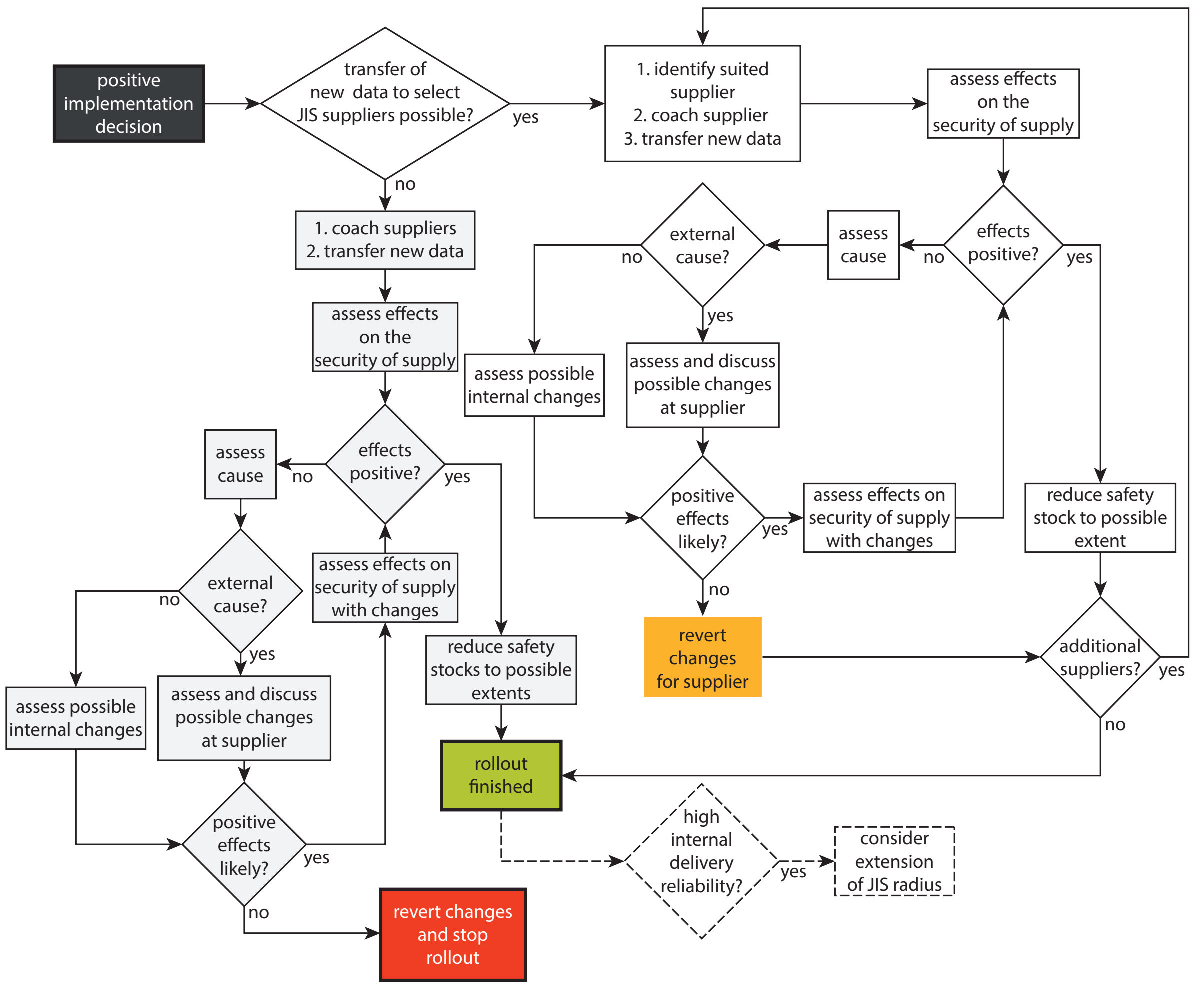

Figure 49: Process map for implementation of the information and coaching of JIS suppliers

For the coaching workshop at the supplier, data needs to be prepared by logistics and supply within Volkswagen. Moreover, the participants of the supplier must include the decision makers of the company in the affected departments of supply, logistics, and production, as well as the controllers and planners who will use the new data. Together the current and future data is compared to the planning time line of the suppliers, and the most appropriate planning for the case at hand shall be chosen. The new data is transferred in parallel to the old data, and the planning parameters are used to virtually produce and ship components.

The next step is assessment of the virtual effects on the security of supply, based on the new data. In the case the effects are positive, the safety stock can be reduced to a reasonable extent for each supplier. Similar to the calculations in section 5.2.1, this extend depends on the delivery reliability and a safety factor based upon the supply distance and the way of scheduling at the supplier. In case the security of supply does not increase, the causes have to be assessed. Internal causes shall be treated and if positive effects are likely, the internal changes' effects on the supply process are investigated. Similarly, for external causes the possible changes to the process are assessed and discussed with the suppliers. If positive effects are unlikely, the changes for the supplier will be reverted and rollout continues with a different supplier.

Upon complete rollout of the process to all JIS suppliers, an investigation on the internal delivery reliability helps to assess the possibility of extending the JIS radius and implementing a new long-distance JIS process. Note that only initial coaching is included in the process map. Periodic coaching of suppliers remains part of the solution, but is not included in the figure. Also note that both process maps are not exhaustive; they only provide a rough overview of a possible activities for implementation.

7.2.5. Sustaining Momentum

Once the first changes are implemented, it is important to stay on top of the developments ahead. Those in charge of the changes are provided with the necessary support. The new behavior also has to be reinforced to ensure steady implementation and that nothing impairs the positive effects of the change. This reinforcement can be done through the proposed workshops in the case of JIS supply, and through recurring assessment of the process KPI and optimization of process parameters in the case of distribution.

Another important factor with regard to sustaining momentum for change is to "stay the course", as Cummings and Worley put it. This means, that it may take some time for the positive effects to surface. Oftentimes positive change is expected immediately, but is more of a medium or long-term development due to learning curves in the process. This is especially true for the change in the distribution department, as it is very important to assess the predictability of the available data rather than jumping to conclusions to minimize the risk of frequent exception handling. Moreover, persistence and focus is required in the change to ensure that its positive effects on the process lasts. If all of the factors described in this chapter are considered during the implementation, successful implementation of the change proposal and thus higher process efficiency and effectiveness are within reach.

8. Conclusion and Recommendations

This thesis described the OTD process of Volkswagen Commercial Vehicles in Hannover and analyzed them along with its sub-processes using the Delft Systems Approach. In the course of the analysis the interdependencies between OTD process and the production order sequence. After the analysis a number of problems were defined, regarding the communication with JIS suppliers, the internal communication with the distribution department, and the scheduling and sequencing process.

Accordingly, a question arose: how to improve the logistics processes and process communication to make the production of vehicles more efficient and effective with regard to the production order sequence, and in due consideration of the current production processes? For the selected problems corresponding solutions were developed to give an answer to this question. These solutions were subsequently discussed and assessed. Validation of the solutions was done qualitatively by experts of the corresponding sections at Volkswagen Commercial Vehicles. Subsequently, an improvement concept combining the two of the three solutions was proposed and the positive effects of the partial solutions were highlighted. Finally, a rough overview of the steps necessary for implementation of the concept was given to support the draft of a detailed and elaborate implementation plan.

In summary, the solutions within the concept proposal provide improvements on the security of supply and reduce the lead throughput time of orders while being cost-effective. Therefore, the implementation of these solutions is highly recommended. Moreover, sequence-shifting provides improvements on the delivery reliability and foundation for the potential implementation of a long-distance JIS process. Though the costs for integration of scheduling and sequencing as proposed are relatively high, there may be other, more cost-effective solutions to make sequence-shifting possible and should consequently be investigated, along with additional feature-related causes for delays.

Concluding, the final improvement concept does not interfere with the production processes currently in place and provides an answer to the question of how to improve the logistics processes and process communication to make the OTD process of the Volkswagen Commercial Vehicles plant in Hannover more effective and efficient.

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Appendix

Improving the Delivery Reliability: Redesign Concept for the Logistics Chain of Volkswagen Commercial Vehicles

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Abstract. Volkswagen Commercial Vehicles uses just-in-sequence production and the resulting complex logistics processes. Especially in the just-in-sequence (JIS) supply of components and the distribution of vehicles by truck large stocks are required due to disturbances in the process. These are cause by unstable production processes, but also low internal delivery reliability. This lead to the question of how the logistics processes and process communication could be improved to make the production of vehicles more efficient and effective. The Delft Systems Approach was used to identify weaknesses in the logistics processes. The analysis showed severe delays for vehicles with non-standard roofs, double-layer paint, and those painted on painting line 1. To mitigate the negative effects of longer throughput times, the early start of these vehicles was suggested. Moreover, the transfer of impractical information for JIS suppliers and their lack of knowledge about the logistics processes at Volkswagen were identified to cause abundant safety stocks. Coaching and proper information for the supplier were proposed to improve the supply process and reduce safety stocks according to the current delivery reliability. Communication was also an issue in distribution, which lead to an inability to plan the shipping of vehicles. This consequently lead to inventory times for truck-shipped vehicles of more than two days. The transfer of production data and the planning of distribution were expected to improve the process. The calculations showed the positive impact of early start of production for the delayed vehicle groups. At the end of painting the median sequence deviation (SQD) was reduced significantly, and an automatic storage and retrieval system (ASRS) could provide a very high service level. Moreover, reductions in safety stocks as a result of JIS supplier coaching and improved data quality lead to notable reductions. Additionally, for the distribution department the ability to plan lead to broad inventory reductions. The calculations showed the positive impact of the three solutions on the processes, though early production is not cost-effective for Volkswagen Commercial Vehicles under the current circumstances. However, the proposal is well-suited for the future implementation of a long-distance JIS process.

Keywords: just-in-sequence production, just-in-sequence supply, process communication, ASRS sizing, delivery reliability

Introduction

Roughly 600 T5 and 120 Amarok leave the Volkswagen Commercial Vehicles plant in Hannover every day. On a regular basis, no two vehicles are identical per day in the pure built-to-order process. This fact leads to complex logistics processes and interfaces in the order-to-delivery process.

Volkswagen uses the just-in-sequence production (JISP) scheduling concept, in which the production sequence is set several days before production [**1**,**2**,**3**]. This allows the order-specific just-in-sequence (JIS) supply in assembly to avoid abundance in strongly diverse component variants. However, the order-specificity also creates a need for sound planning of the production process to distribute the workload and provide for high utilization of the labor-intense assembly section. Moreover, completed vehicles have to be shipped to the specific customer quickly to ensure short lead times.

All of these processes are strongly dependent on both the production schedule and the actual production order sequence. Inaccuracy in planning and discrepancy in the production utilization cause deviations from the target schedules. Furthermore, process disturbances induce sequence deviations, which means the output sequences of the different production sections of body construction, painting, and assembly lapse. Restoration of the sequence at the end of the sections mitigates the impact of sequence deviations, but only to a certain degree. At Volkswagen Commercial Vehicles the ability of the automated storage and retrieval system (ASRS) to restore the sequence deviations before assembly is exceeded by far.

Hence, the actual assembly sequence differs from the plan sequence, which makes changes in the supply of JIS components necessary. For this reason the JIS suppliers outside a 5 km radius have to make use of a third level logistics provider (3PL) for storage and sequencing of components. Moreover, because many JIS suppliers use the target completion schedule for their production scheduling, the aforementioned inaccuracy of the target schedules also leads to imperative safety stocks at the 3PL. These safety stocks range from 1.5 to eight days, dependent upon on the supply distance [**4**]. The total stock volume of JIS components at the 3PL is 3896m^3. For the future, direct JIS supply is proposed for distances greater than 5 km, which promises substantial cost-savings [**5**].

The distribution department also receives the target schedule; as a preview for vehicles to be shipped. Adversely, the inaccuracy results in an inability to plan ahead and thus in large inventory of finished goods, particularly for vehicles to be shipped by truck. The latter currently have inventory times of 2.19 days. This yields average inventory levels of 694 vehicles to be shipped by truck.

Data for production from 04-03-2013 to 19-04-2013 showed that large deviations from plan sequences, develop within the production processes, and especially for T5 with non-standard roof (NSR) in body construction, and for those with double-layer paint (DLP), or painted on painting line (PL) 1 at the end of the painting process.

Figure 1 shows the sequence deviation (SQD) for T5 with NSR compared to those with a standard roof. The SQD for regular T5 (excluding NSR) and those with DLP or painted on PL 1 are illustrated in Figure 2.

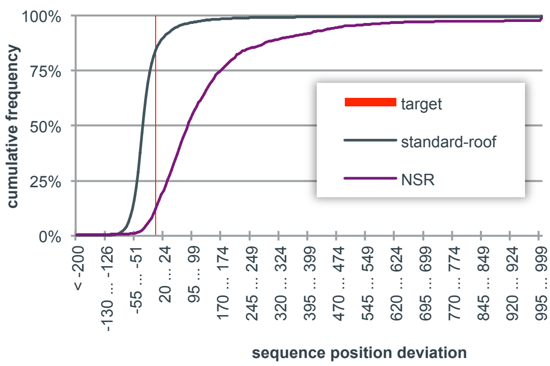

Figure 1: Current sequence deviation, end of body construction (16752 vehicles)

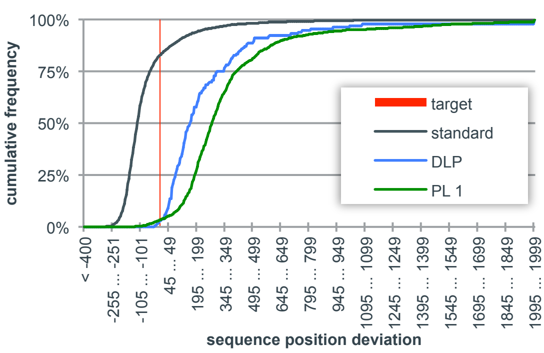

Figure 2: Current sequence deviation at the end of painting (15693 vehicles)

Changes in the production process are currently not up for debate, but process interfaces and communication structures provide a framework for potential improvements on both sequence deviations and their effects on the logistics processes.

The main question is how the logistics processes and process communication can be improved to make the production of vehicles more efficient and effective with regard to the production order sequence and in due consideration of the current production processes.

Methods

Basically, two approaches for improvement are considered. On the one hand, the negative effects of schedule and sequence deviations on the supply and distribution process are mitigated. On the other, the causes for deviations of the sequence within production are treated.

For the analysis of the processes' interfaces and communication the Delft Systems Approach (DSA) [**6**] was used. Due to the large inventories in JIS supply and distribution, there was a special focus on the related processes. Moreover, special attention was also given to the scheduling and sequencing to find potential causes for the severe sequence deviations.

Among the underlying causes of deviations from the target schedules and plan sequence – especially in assembly – are the unstable production process in painting with high quality standards, but also the negligence of additional labor for vehicles with NSR in body construction, the systematic rerun of vehicles with DLP in painting, and the longer throughput times of PL 1. The median sequence position deviation for NSR vehicles at the end of body construction and for DLP and PL 1 vehicles at the end of painting were delays of 97, 221, and 271, respectively.

To mitigate the negative effects of longer throughput times on the assembly sequence, adaption of the sequencing for the beginning of production is necessary. Shifting production to an earlier point in the sequence for those vehicles with longer throughput times is expected to be beneficial for the overall delivery reliability. Therefore, the vehicles with expectedly longer throughput times are released into production early by the number of sequence positions corresponding to their respective median delay.

To assess the effects on the sequence, the orders from the analyzed dataset were given a sequence number s from 1 to n (16752 and 15693 for body construction and painting, respectively). From this number the median was subtracted. The resulting new position number n was then sorted ascending, and a new sequence number sn was given to the orders to emulate earlier order-release in body construction and to eliminate overlaps. The difference between old and new sequence numbers s and sn was then subtracted from the old sequence deviation (SQD) to compute the new emulated SQD. Additionally, approximation calculations based on Inman [7] are used to estimate the required number of dedicated order resorting cells in the ASRS between painting and assembly that can be achieved as a function of the service level. In these calculations, a certain number of orders – corresponding to the service level – with the largest SQD are ignored to approximate the number of cells required in the ASRS for the service level.

The DSA analysis showed weaknesses in communication between Volkswagen and JIS suppliers, as well as between production and distribution within Volkswagen. This communication needs alteration to treat the symptoms of large inventories in the JIS supply and the distribution of vehicles, which are caused by the low adherence to target schedule and plan sequences.

With regard to JIS supply, the proposed changes include the transfer of more relevant to the supplier. This means that suppliers shall receive target assembly dates rather than target completion dates. This is of special importance for direct JIS suppliers, who do not use a 3PL. Moreover, rather than sending the plan sequence for body construction, the plan sequence for assembly shall be sent six days prior to assembly.

Disturbances may always lead to unavailability of vehicles or parts for assembly and thus changes in the assembly sequence. Hence, it is important for suppliers to know accuracy of data transferred at different stages to plan production of their components accordingly. Discussions with suppliers, however, exposed that there is a severe lack of knowledge about the data that is transferred and the information it provides. Due to this ignorance, the production scheduling is based on the inaccurate target completion schedules. The result is lack of conformity between supply and demand, which creates a need for large safety stocks.

An approach to foster knowledge and thus increase the security of supply and render safety stock reductions possible is the coaching of JIS suppliers. In coaching workshops suppliers can be informed about the data transferred and the information implied. Based on this new knowledge, the workshop participants of both Volkswagen and the supplier can work out a scheduling concept for component production. This way the optimal process for each supplier can be developed and the production and supply of components meets the actual needs.

These improvements of the JIS supply process directly lead to an increase in the security of supply. The safety stocks can subsequently be reduced to a reasonable level for each supplier. This level strongly depends on the delivery reliability within Volkswagen. Currently, about 0.1% of all T5 enter assembly no earlier than 310 sequence positions. Therefore, the safety stocks can be reduced from the current values to 310/600 multiplied by a safety factor (SF). In the case of JIS suppliers in Germany with distances greater than 90km, a SF of 2 to 3 is assumed to be adequate. This yields a safety stock range of 1.03 to 1.55 days, which corresponds to a reduction of 48 to 66% for these components.

With regard to the distribution of vehicles, there is a severe lack of information for distribution regarding the status of vehicles. This lack of information leads to an inability to plan the distribution prior to vehicle completion. After completion of the last vehicle in a destination batch the freight forwarders have two days time to pick up these batches, and thus the average inventory times for these vehicles are much longer than for vehicles shipped by train.

Therefore, the additional transfer of sequence-related data for controlling and monitoring to this department is proposed. This means the plan sequence for assembly, and the actual sequences in body construction and assembly shall be sent to distribution to indicate the probability of completion within a certain timeframe for specific vehicles. Complementary, information on shipping-relevant data such as size, weight, destination, and planned treatment after completion on the production line, as well as on blocking of vehicles in production shall be transferred. Moreover, additional completion information for vehicles that receive special treatment shall be also sent to distribution.

The new quality and quantity of information provides an ability to plan shipping ahead of completion. Hence the average inventory times for vehicles shipped by truck may be reduced. While there is currently insufficient data on the probability of vehicle completion within a certain timeframe, the average inventory times for these vehicles can presumably be reduced to 1.5 days.

Results

The calculations of the emulated new SQD showed severe reductions of the median SQD. The median SQD for the entire observation period shift towards the target of zero deviation for all characteristics, as Table 1 shows. In body construction, the median SQD for all vehicles shifts from 26 to 4 positions early, in painting the median shifts from 100 to 75 positions early.

Table 1: Medians before and after sequence-shift

end body construction		standard roof	NSR	all	
	before	-29	86	-26	
	after	-5	13	-4	
end painting		**standard**	**DLP**	**PL1**	**all**
	before	-115	165	282	-100
	after	-81	-22	31	-75

These values are also confirmed by Figure 3 – showing the results of sequence-shifting at the end of body construction – and Figure 4 – at the end of painting.

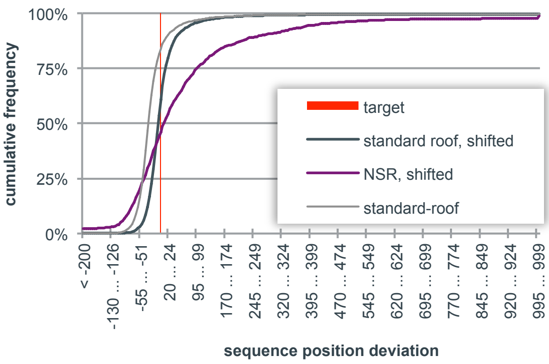

Figure 3: Sequence deviation at the end of body construction with sequence-shifting (16752 vehicles)

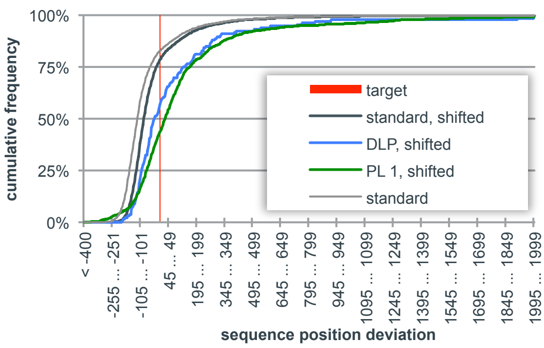

Figure 4: Sequence deviation at the end of painting with sequence-shifting (15693 vehicles)

Note that the 0.1%-SQD-value used for determination of the safety stock diverges from the target; from -310 to -335 sequence positions. Also note that the cumulative frequency of vehicles delayed by less than one day at the end of painting increases only marginally, from 97.4% to 97.9%, which corresponds to 3 vehicles. The approximation calculations show that with the new SQD the number of dedicated cells in the ASRS needed for a specific service level decreases from by 48 to 61 through sequence-shifting; for 95%, for example, from 341 to 286. Alternatively, the ASRS can achieve a theoretical service level of 92% with 322 cells in the current situation, as opposed to 98% with 320 cells with sequence-shifting.

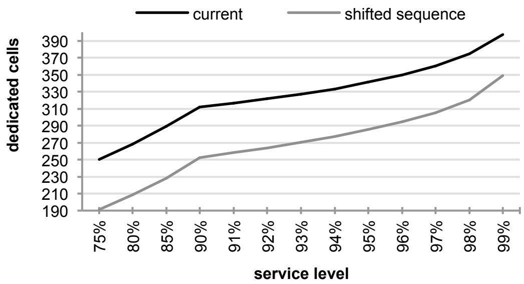

Figure 5: Service levels vs. number of dedicated reordering cells in ASRS

The reduced safety stocks of the changes in the JIS supply process yield reductions of $1088m^3$ and $802m^3$ for SF = 2 or SF = 3, respectively. Note that adaption of safety stocks are only applied to JIS suppliers in Germany outside a 90km range, as Table 2 shows.

Table 2: 3PL stock reductions for T5 JIS suppliers

location	3PL stock [m³]		
	current	SF = 2	SF = 3
GER, < 90 km	690	690	690
GER, ≥ 90 km	**1659**	**571**	**857**
neighboring countries	120	120	120
rest of Europe	1427	1427	1427
total	**3896**	**2808**	**3094**

Calculations for the inventory of vehicles shipped by truck show reductions of 22% or 219 vehicles. Table 3 shows the respective values for T5 and Amarok according to the current process data and the assumed reduction of inventory time. Note that of all vehicles, 50% are shipped by train, 44% by truck, and 6% are picked up at the plant.

Table 3: Inventory reductions in distribution

	T5	Amarok	total
t, inventory train [d]	0.8	0.8	0.8
t, inventory truck [d]	2.19	2.19	2.19
inventory [vehicles]	818	164	982
t, inventory truck, reduced [d]	1.5	1.5	1.5
inventory, reduced [vehicles]	636	127	763

Discussion

The results for sequence-shifting of vehicles with NSR, DLP, or painted on PL1 show significant improvement of the delivery reliability. This holds especially for the vehicles affected directly, but also extends to the remaining vehicles. On average, early production is less early, while late production is not as late as it is without sequence-shifting. Further improvement of the JIS supply process cannot be expected by the introduction of sequence shifting, however, as a few early orders come even earlier with sequence-shifting. Moreover, as vehicles are assumed to be in the inventory in distribution for more than one day, the reductions in delays have little effect on this process. Therefore, large reductions in the inventory of completed vehicles cannot be expected, either.

Nevertheless, the approximation calculations for the service level in the assembly sequence propose a significant improvement over the current service level. However, these calculations do not take the current restrictions into account, which prevent an entirely elective selection of orders for assembly. Conveniently, the tendency of significant increase in the service level for assembly remains.

In the situation of Volkswagen, there is another issue that impairs the implementation of sequence-shifting. Large investments are necessary to change IT and processes for scheduling and sequencing. The cost-effectiveness of sequence-shifting is not given, because the higher delivery reliability and the increased service level in assembly do not directly result in cost savings. Therefore, the implementation is currently not recommended. However sequence-shifting provides a framework for the potential implementation of a future long-distance JIS supply process, which requires a high service level in assembly.

With regard to the proposed changes in the JIS supply process, the calculations show significant reductions in area requirement at Volkswagen's 3PL. These area reductions alone correspond to annual savings of €10,000 to €14,000. With expected costs of roughly €9,000 per year for coaching of the affected suppliers, the proposal is also cost-effective. In addition to the savings, additional components may be supplied as JIS components through the 3PL, as the area becomes available. Moreover, the auxiliary procurement costs include charges for capital employed in the safety stocks at the 3PL. Hence, the safety stock reduction provides grounds for reduction of these costs, making the proposed changes even more cost-effective.

As the results show, the changes in the distribution process also provide for a positive development for Volkswagen. The annual savings corresponding to the assumed reductions in area requirement are about €13,700. But area itself is a valuable commodity with the imminent construction of an additional press plant on the plant site. Therefore, the expected investment of €13,000 for the process changes are expected to be well-invested. Especially, since renting of external area for inventory of completed vehicles makes it impossible to just drive the vehicles over from production without a proper registration. Consequently, the changes in the distribution process are recommended for the Volkswagen Commercial Vehicles plant in Hannover.

In conclusion, the proposed solutions help to improve the delivery reliability in production and the utility of the logistics processes. Moreover, the cost-effectiveness of the coaching of JIS suppliers and the transfer of additional production data to distribution was shown. Cost-effectiveness of sequence-shifting is currently not provided, but its implementation provides a substantial framework for the implementation of a long-distance JIS process. Hence, making the implementation of sequence-shifting a strategic decision.

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Appendix B. Production System and New Logistics Concept

The KPS, however, is currently not implemented on all levels of the organization yet. The basics for these pillars are a balanced and smooth production, consequent elimination of waste of any kind, standardization, organization of work, and environmental protection. Figure 50 illustrates the production system with its basics and principles.

Regarding the principles of the KPS for logistics, the tact pillar focuses on clocked delivery both inbound and in-house. The flow deals with short cycles, supermarkets, and milk-runs, while the pull pillar includes Kanban control between supermarkets and installation location, and demand-driven ordering from suppliers. The last principle of perfection comprises just-in-sequence production, visualization, and controlled provision of material at the assembly lines.

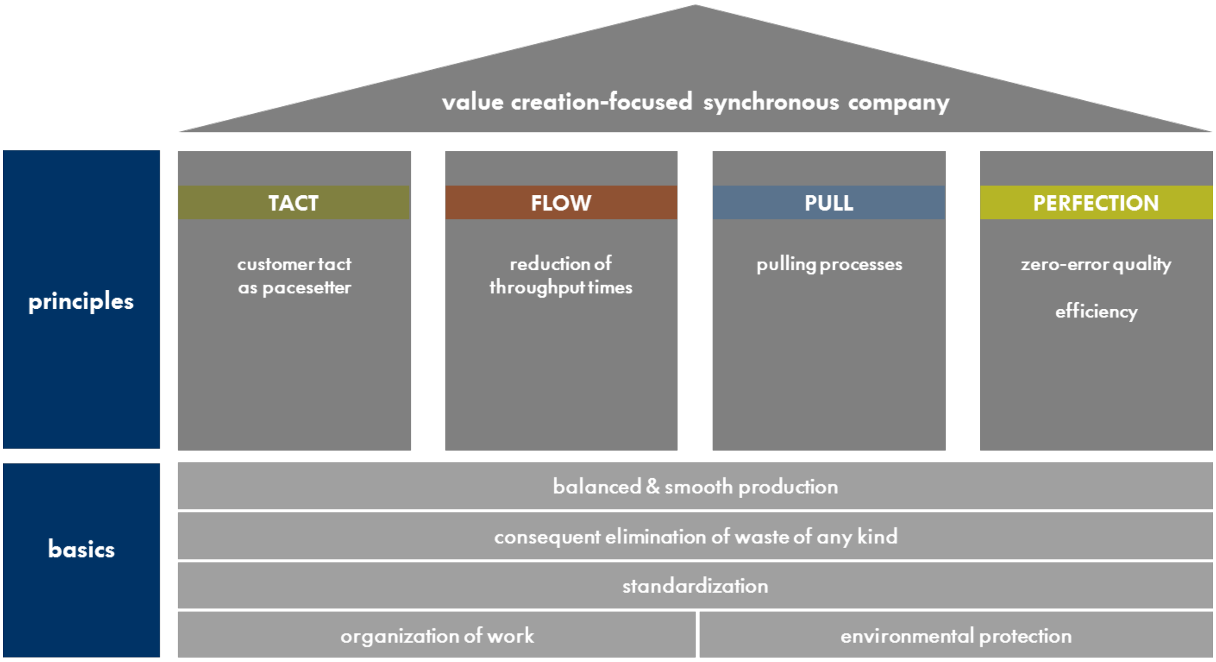

Figure 50: The Volkswagen Group production system[54]

The basics of the Volkswagen Group production system for logistics include smooth transport and order quantities for the balanced and smooth production, reduction of efforts in control and administration, and controlled order delivery quantities for the consequent elimination of waste. Standardization is implemented by means of complete processes of the new logistics concept (NLK)[55], described briefly in the following paragraphs, while the organization of work means for the production that control processes with exception handling have to be used. Finally, environmental production includes the avoidance of packaging and ideal utilization of truck capacity.

[54] illustration based on Volkswagen AG [54]
[55] from German: Neues Logistik Konzept

In the course of this production system, a new logistics concept was developed and is currently being implemented step by step within the Volkswagen Group. In the NLK there are a number of fields of action[56] (FoA), with the first ones being the order system and balanced production. Field of action 1a, the order system, covers the consumption-driven orders via Kanban and the pulling and clocked order calls, and thus mostly the information flow from Volkswagen to the suppliers. This includes the generation of time tables for deliveries by means of a bus principle, as well as the weekly provision of suppliers with updated production forecasts up to 6 months before installation with shipping dates rather than the currently used delivery dates. FoA 1b regards both the stability in planning that sets weekly schedules and the stability of the sequences in production. These two factors together provide the balanced production striven for by the Volkswagen Group.

The second field of action concerns in-house logistics. In the course of the NLK, so-called supermarkets[57] provide limited amounts of material to the assembly line more frequently to improve efficiency and ergonomics. Provisioning happens with clocked trailers for less traffic and optimal use of capacities.

FoA 3 seeks to improve the inbound logistics. This means the material flow from suppliers, potentially via crossdocks[58], to the goods receipt of the plant. By means of milk-runs the costs for transport may also be reduced, while the frequency of supply by low-volume suppliers can be increased.

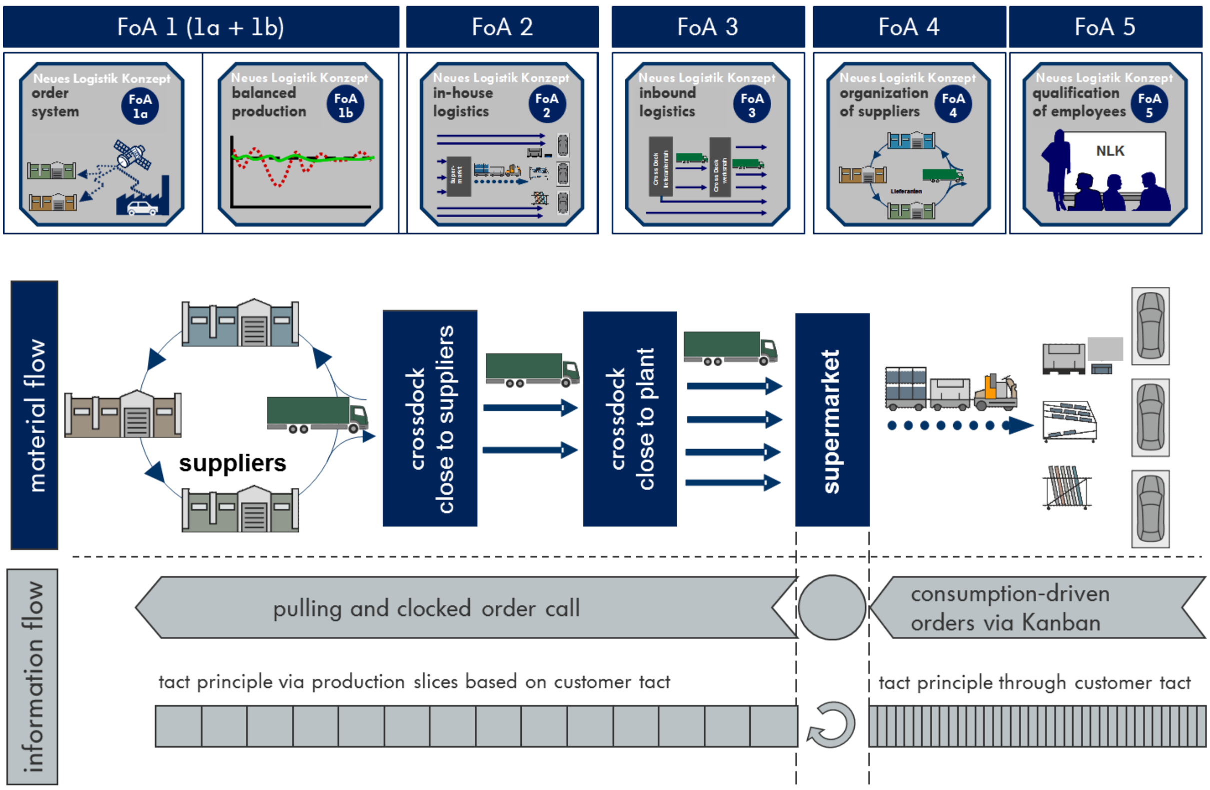

Figure 51: Fields of Action (FoA) of the new logistics concept (NLK)[59]

[56] in German: Handlungsfeld (HF)
[57] a logistics system close to production, used for picking and sequenced delivery of parts [12]
[58] regional terminals for the consolidated supply or distribution of goods [12]
[59] illustration from Volkswagen Nutzfahrzeuge [42]

In the fourth field of action the suppliers are to be qualified and new agreements are made to ensure the supple implementation of the new supply concepts. Furthermore, FoA 5 seeks to qualify internal employees on all levels of the organization to raise awareness on the importance and utility of the new concepts, and shows workers how to implement the concept in their corresponding areas of expertise [42].

In addition to the five fields of action in the figure, there is also a sixth FoA for the distribution of vehicles to dealers and customers. In this area, the NLK dictates to route finished vehicles via centralized depots and hubs to subsequently deliver to dealers based on a pull-signal initiated by the customers [43].

Appendix C. The Order-to-Delivery Process

Figure 52 shows another illustration of the order-to-delivery process. The upper stream shows the information flow on different levels, from the dealers column on the right via sales, development, purchasing, logistics, and production to the suppliers column on the very left. The lower stream shows the material flow, starting with parts and components from the suppliers and results in delivery of the finished vehicle to the customer. Note that in the figure the core steps of the OTD are dark blue, while the supporting process steps are light blue.

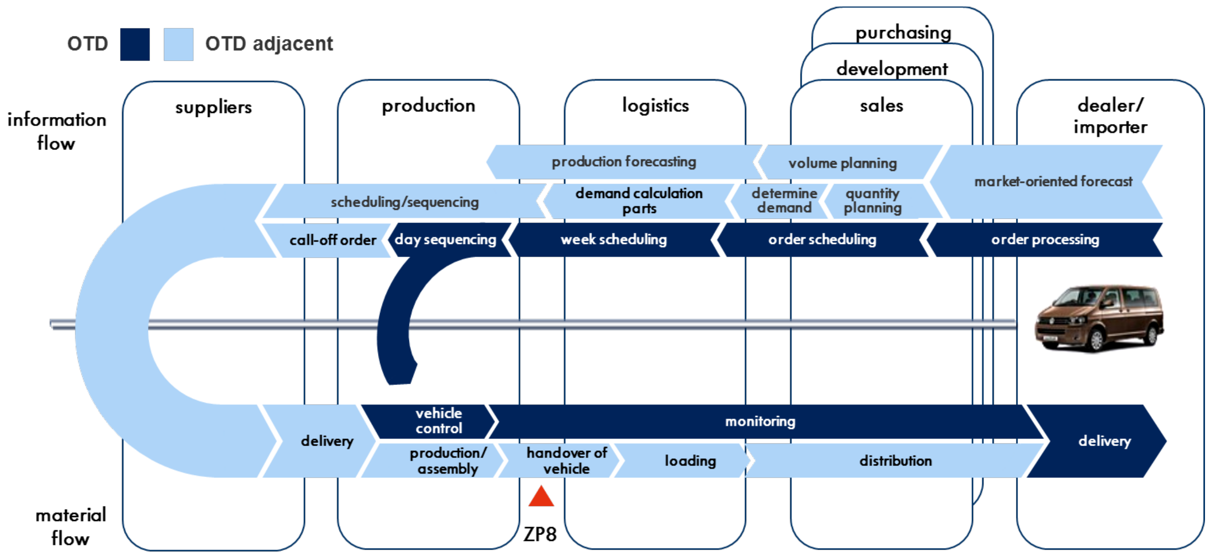

Figure 52: The order-to-delivery process visualized[60]

[60] illustration based on Volkswagen AG [62]

Appendix D. Selection Criteria for Scheduling and Sequencing

Table 16: Planning and scheduling systems and criteria

system	IFA	SONATA3	FIS DISPO II		
input criteria	weekly capacities (level indicators)**	assembly selection criteria	body construction selection criteria	painting selection criteria	assembly selection criteria**
	• Multivan • engine • gearbox • A/C • paint type • 4Motion • etc.	• color (block)*	• wheelbase (block) • NSR	-	• 2nd sliding door (BL) • right-hand drive (BL) • NSR (BL) • 4Motion (BL/CL) • hitch (BL/CL) • camper/beach/startline (CL) • elevating roof (CL) • sliding door left (CL) • comfort control panel (CL) • roof rack (CL) • 2nd battery (CL) • long wheelbase (CL) • seat bench (CL) • head airbag (CL)
output	weekly completion schedule	daily completion schedule	section specific sequences		

* Amarok only ** examples for T5; CL = comfort line (Multivan), BL = basic line (Transporter)

Appendix E. Just-In-Sequence Production Scheduling Concept

Setting the production sequence and thus also the supply and distribution sequence at a rather early stage is a concept known under various terms, such as the in-line vehicle sequencing (ILVS) [44,45,46], pearl chain manufacturing organization[61] (PCMO) [47], or just-in-sequence production (JISP) [48,49].

Adjacent to above terms are those for the synchronous supply of parts based on the production sequence: supply in line sequence (SILS) [50,46], sequential parts delivery (SPD) [44,45,46], or just-in-sequence supply [51]. For the sake of simplicity, the terms just-in-sequence production and just-in-sequence supply will be used in the remainder of this thesis.

The conceptual roots of JISP lie in Japan, where Taiichi Ōno developed a new production concept for the Toyota Motor Corporation, the Toyota Production System (TPS), in the 1950s [46]. Among the well-known production principles developed and incorporated by Ōno are just-in-time (JIT), the Kanban system, production smoothing, and pull-production [52]. From the growth of customization options vehicles and the number of different vehicles a need for a slightly different approach emerged.

Due to the savings potential of just-in-time supply and the associated reduction of costs for stockage areas and stock quantities, the JIT supply had to be extended. As JIT supply refers to the right product at the right time in the right location, there is no problem for homogenous materials. However, due to customer-induced differences in vehicles and the tendency to source entire components from external suppliers, the components have to be supplied in the order that corresponds to the order of vehicles passing the assembly line. Just-in-sequence supply and just-in-sequence production together cover this need and provide the ability to control the synchronous flow of vehicles and parts.

[61] The German Association of the Automotive Industry uses the German term *Perlenkette* [26].

Just-in-sequence production is defined by the German Association of the Automotive Industry[62] as the practice of planning both sequence and all characteristics of a vehicle during scheduling [26]. This corresponds to the practice at Volkswagen Commercial Vehicles, as described in 2.4.3, and many other companies within the automotive industry [12]. Ford implemented this concept in 1989 in Saarlouis [27], Audi in Ingolstadt in 1992 [28], and Volkswagen Commercial Vehicles in Hannover in 2005 [29].

Controlling and Monitoring of Just-in-Sequence Production

For controlling of the processes, one must be able to measure something and compare this to certain standards. With regard to the question of what to measure, there are different approaches. Weyer [30] defined a set of seven key figures for controlling of the sequence with regard to the maintenance of the sequence and both due-date and content wise performance. Two of which are designated to maintain the sequence. However, the sequence quality of the pearl chain (RFG_{PK})[63] only describes what percentage of the vehicles is not exactly in sequence and how many gaps develop in the sequence and the position bandwidth quality of the pearl chain (PBG_{PK})[64] only describes the extent of the largest deviation from the sequence. For maintenance of the sequence, these figures are insufficient.

The measurement of due-date wise performance is done using the target due date quality of the pearl chain (STG_{PK})[65] the plan due date quality of the pearl chain (PTG_{PK})[66] and the production delivery reliability (PLT)[67]. Both STG_{PK} and PTG_{PK} compare the actual sequence of produced vehicles to a previously determined sequence. While the STG_{PK} uses the initial target sequence as some sort of a forecast, the PTG_{PK} uses the rather short term plan sequence, which is usually used for call-off orders of JIS modules to determine the rate of vehicles produced within a certain period in which they were supposed to be produced. These values are of special importance with regard to the supply process and can help to prevent a bullwhip effect in the supply chain [30].

The production delivery reliability investigates the adherence to the schedule over a longer timeframe and provides the rate of vehicles completed within, for example, a certain day. This key figure is not only important for the entire order to delivery process due to the dependency of the delivery date to the customer, but also to the distribution department. A large value of production delivery reliability provides for a large ability to plan the shipping process and reduce costs due to shorter storage times.

According to Weyer, the content-wise performance of sequencing can be measured using the model mix quality of the pearl chain ($MmixG_{PK}$)[68] for both equal distribution and grouping of characteristics. The production block-related $MmixG_{PK}$, however, only provides the average size of production blocks for certain characteristics such as colors. The key figure for evaluation of equal distribution of characteristics provides a monetary assessment of the additional costs for violations of restrictions, such as the minimum number of left-hand drive T5 between two right-hand drive T5.

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[62] Verband der Automobilindustrie (VDA)
[63] from German: Reihenfolgegüte der Perlenkette
[64] from German: Positionsbandbreitengüte der Perlenkette
[65] from German: Sollterminreihenfolgegüte der Perlenkette
[66] from German: Planterminreihenfolgegüte der Perlenkette
[67] from German: Produktionsliefertreue
[68] from German: Modellmixgüte der Perlenkette

Contrary to Weyer, Meißner [32] defines a set of different key figures split in two groups: planning key figures and control key figures. [The five key figures for a stable sequence are the sequence adherence (RFE)[69], the sequence deviation (RFA)[70], the sequence backlog (RR)[71], the sequence quality (RFQ)[72], and the first in (system) first out reliability. The RFE is the percentage of vehicles not delayed in the sequence and provides a basis for average resequencing efforts and the average frequency of scrambling[73] of the sequence.

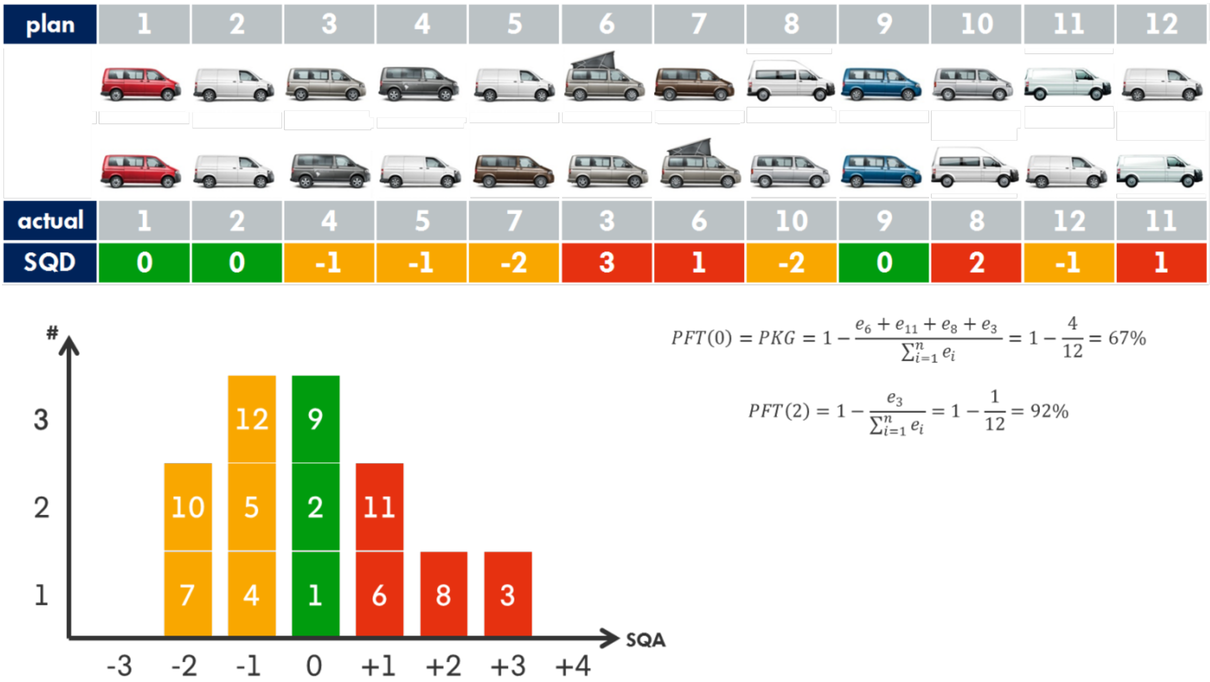
Meißner also stresses the importance of defining what the actual sequence is compared to; the input sequence of the sub-process or the plan sequence. The differentiation between the two allows a number of additional analyses on sub-process level rather than only examining the entire process. Therefore, the sequence deviation per order can be expressed as a relative or absolute value for deviation from the input or plan sequence, respectively. The frequency distribution of the RFA provides a sound overview of frequency and intensity of deviations from the sequence over a period of time and will be treated later in this chapter in more detail. Moreover, the average of the RFA's modulus can be used to measure the average intensity of deviations from the sequence. On order level, the RFA can also be used to control resequencing buffers and the flow of vehicles, for example in the case of large backlog.

Information on backlogging can also be gathered from the sequence backlog key figure. It provides a preview on future delays and can be used to size resequencing buffers for components. The ratio between orders without sequence deviations and target work in process is expressed in the sequence quality, which can be very helpful in evaluation of the scrambling intensity of particular processes. Lastly, Meißner provides the first in first out (FIFO) reliability and the first in system first out (FISFO) reliability. While the FIFO reliability is concerned with a section's adherence to the actual input sequence, the FISFO reliability investigates the entire process' adherence to the plan-sequence. To accomplish this, both FIFO and FISFO reliability calculate the current percentage of vehicles not delayed or missing in the respective input or plan-sequence. Therefore, these key figures can be used for controlling, as reliabilities are current values rather than being calculated historically.

Volkswagen, however, rather uses the sequence window reliability (PFT)[74] and the sequence performance (PKG)[75] over a production day (from 6 a.m. to 6 a.m.). The PFT is the percentage of vehicles not missing or delayed from the plan-sequence by more than a specific number of elements in the actual sequence, where the specific number of elements is a tolerance value of sequence deviation and expressed as a parameter w of the sequence window reliability: PFT(w). The sequence performance is essentially the sequence window reliability with no tolerance, that is PFT(0) = PKG.

[69] from German: Reihenfolgeneinhaltung
[70] from German: Reihenfolgenabweichung
[71] from German: Reihenfolgenrückstand
[72] from German: Reihenfolgenqualität
[73] one speaks of scrambling when deviations from the plan-sequence occur
[74] from German: Perlenkettenfenstertreue
[75] from German: Perlenkettengüte

Note that this PFT only takes late deviations into account and neglects early production of orders, which are regarded to be a result of other orders' late production. Moreover, Volkswagen also creates frequency diagrams of the absolute sequence deviation (the actual position from the position in the plan-sequence) as described by Meißner. A fictional example of such a diagram is shown in Figure 16.



$$PFT(0) = PKG = 1 - \frac{e_6 + e_{11} + e_8 + e_3}{\sum_{i=1}^{n} e_i} = 1 - \frac{4}{12} = 67\%$$

$$PFT(2) = 1 - \frac{e_3}{\sum_{i=1}^{n} e_i} = 1 - \frac{1}{12} = 92\%$$

Figure 53: Fictional sequence deviation histogram

On the top of the figure, the plan sequence, actual sequence, and the resulting sequence deviation are shown. The RFA's background color orange implies early production, while red implies late production. Note that in the evaluation period from plan position 6 to 25, there are only four vehicles produced on time. One can also see that the sequence quality window with parameter 10 is 95%, as no order is delayed by more than 10 positions, but order 25 is outside the evaluation window. Order 6 is outside the window as well, but produced already and thus not counted in the determination of the PFT. Similarly, the PFT(2) is 85% due to orders 3 and 18 being more than 2 positions late and order 25 missing. The sequence performance, as mentioned earlier, is the PFT with parameter 0 and 60% in this example, due to 7 late orders and 1 order missing.

Volkswagen uses these two key figures and the sequence deviation frequency diagrams to evaluate the processes and determines the values based on the plan-sequence in assembly, as this is considered to be the most crucial and cost-intensive part of production. Moreover, JIS parts are installed in assembly only, making this part most interesting for investigations with regard to JIS supply.

The completion dates, however, are also important. The production skew reflects the vehicles delayed in their completion date, where the length of the production skew is the maximum number of weeks of delay and the production skew volume is the number of vehicles delayed by at least one day. This also means that vehicles planned for Thursday night, for example, are considered in the production skew on Friday morning already. In the sequence deviation histograms the skew cannot be visualized properly. The mathematical skewness of the histogram, however, gives an indication of the degree to which orders with backlog are delayed, which indirectly corresponds to the production skew.

Current Key Figure Values

The just-in-sequence production scheduling concept has been in place at the Hannover plant of Volkswagen Commercial Vehicles since April 2005. The use of the key figure sequence performance, however, was introduced in 2008 [33]. Since then the adherence to the schedule at the beginning of assembly improved drastically. While in 2008 the sequence performance of T5 production at checkpoint LH00[76] was only 46% [34], while exactly five years later the sequence performance at the same counting point was 67% [35]. Additional values of the key figures (see section 2.5.2) can be found in Figure 17 for week 6 of 2013.

Table 17: Assessment of different key figures and checkpoints for week 6 of 2013

key figure	R150	R900	R950	LH00	M100
SWR(0) = SP	34,9%	81,4%	79,0%	69,4%	71,6%
SWR(10)	97,1%	83,4%	82,4%	70,5%	72,5%
SWR(50)	97,5%	87,6%	88,2%	74,1%	75,6%
SWR(100)	98,0%	89,0%	89,8%	77,7%	78,5%
SWR(400)	99,8%	97,8%	98,4%	93,2%	93,2%
StdDev(SQD)	56	130	116	284	286
Avg(ABS(SQD))	9	76	66	189	184

The low value of 34.9% for the sequence performance PKG at the beginning of body construction (checkpoint R150) can be explained with few orders that were produced much earlier than initially planned and a large number of orders being delayed by less than 10 positions, as the PFT(10) at the same checkpoint is 97.1%. Figure 17 also shows that the FIFO buffer between the end of body construction (R900) and the beginning of painting (R950) is able to reduce the number of large deviations from the sequence, but actually increases the number of small deviations.

The ASRS with elective access between the end of painting (LH00) and the beginning of assembly (M100), however, can restore the sequence much better for both large and small deviations from the plan sequence. As the increase of the PKG and PFT(100) show. Nevertheless, the ASRS was unable to increase the PFT(400) for the same segment due to its low fill level of somewhere between 50 and 150 vehicles in the considered period.

Appendix F. The Delft Systems Approach

The processes described in section 2.4 are analyzed in this section of the report. For the graphical representation of the processes the Delft Systems Approach (DSA) will be used, which shows both material and information flows. It was initially described in 1975 in the Netherlands by in 't Veld as the *Delftse Systeemkunde* [37] and subsequently translated to English and extended to its current form as the Delft Systems Approach by Veeke, Ottjes, and Lodewijks [36] to meet additional needs for process analyses.

[76] for this period the sequence performance is available for checkpoints R150, R950, and LH00 only

The Delft Systems Approach helps researchers to identify the correct problems and consequently solve the problems correctly. In order to identify the problems a system is defined by the researcher, with the system being a collection of elements within the universe with mutual relationships and relationships with other elements from the universe. Within these systems the elements are the smallest parts considered by the researcher, and the collection of all elements is referred to as the system's content. Relationships between elements denote interaction between the elements and thus elements can influence each other. The relationships between elements within the system form the internal structure of the system, while relationships between the system's elements and elements outside the system form the external structure. The external elements form the environment of the system; the part of the universe that interacts with elements within the system. [36].

A system has a function that fulfills a need within its environment. This need is connected to a number of requirements according to which the system transforms a certain input to a desired output. The degrees to which the requirements are met are reflected in the performance of the system. A basic diagram that shows a system and its input, transformation function, output, requirements and performance can be seen in Figure 54 and is called steady state model. Note that the information flows are depicted with thin arrows, while thick arrows denote flows of matter.

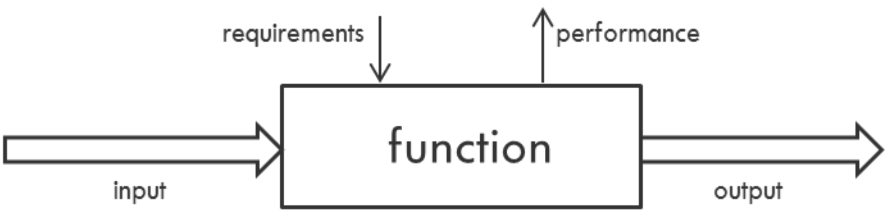


Figure 54: Basic function model, illustration based on Veeke, Ottjes & Lodewijks [36]

Deeper analysis of the transformation function reveals additional elements as shown in Figure 55. A grouping of elements called function control translates requirements into standards and results into performance values, which are used by another group called process control. Process control takes care of the continuous adherence to standards and takes actions to enforce them whenever necessary, while function control adjusts the standards according to changed requirements or evaluation of the results on a long term.

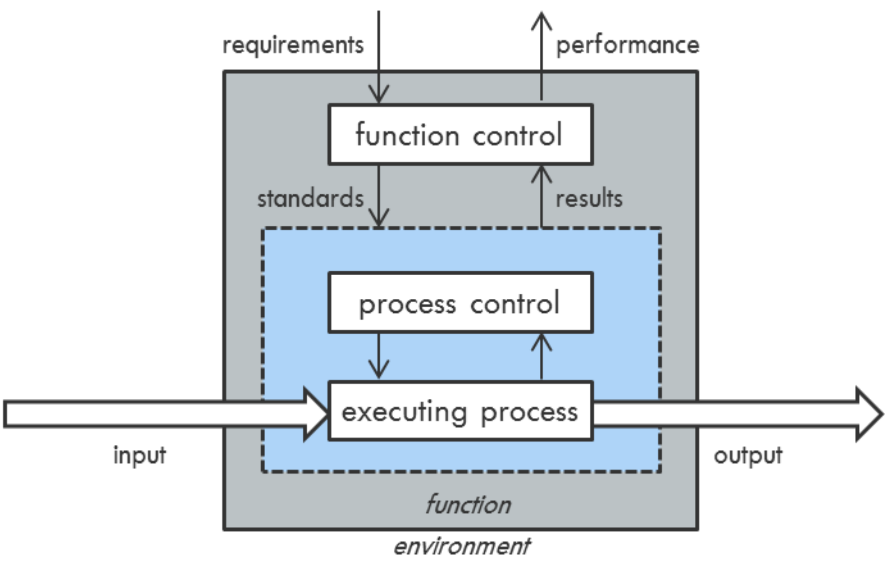


Figure 55: Steady state model with function and process control, based on Veeke, Ottjes & Lodewijks [36]

Appendix G. Identified Problems

In addition to the three problem categories in chapter 4, the following problems were also identified during the process analysis of this thesis.

Problems in the (1) Product Variance

One of the key elements of just-in-sequence production is late order assignment (see section 2.5). In the production of both Amarok and T5, however, the car bodies are assigned to a specific order at the beginning of body construction. This **(1.1) early order assignment** results in the fact that scrambling of bodies directly results in scrambling of the order sequence and thus impedes the positive effects of JISP.

If late order assignment was implemented for the Amarok, the **(1.2) early generation of variants using emblems** in the paint shop had a very negative effect on the product variance of painted bodies. The marginal difference of bodies due to TDI, 4MOTION, or BlueMotion emblems causes a large creation of variance before assembly. However, if late order assignment is not implemented, this problem of early variant generation can be neglected.

Problems in the (2) Production Structure

The **(2.1) production structure in painting** is another problem. The sheer amount of vehicle models with different sequences moving over one filler line requires large buffers for adequate provision of vehicles to the downstream processes for a good utilization both before and after the mutual preparation line. Though this does not influence the sequence as much, it does require expenditures for the infrastructure and control of the large buffers.

(2.2) Advance production is another problem in production and leads to unavailability of parts for production orders. The cause for this is the section-specific optimization of processes, especially in assembly, and thus the full utilization of the downstream processes. This results in low adherence to the schedule suppliers use. In addition to aforementioned effects, the distribution department is also affected negatively as advance production deprives the distribution department of the ability to plan with the initially planned vehicles.

Problems in the (3) Control of the Vehicle Flow

As mentioned earlier, there are more weaknesses to be found in the production process. One of which are randomized **(3.1) quality checks of delayed vehicles** (see section 2.4.5). The quality checks are, as the name reveals, randomized and thus do not take delays into account. These delayed vehicles are then delayed even further, which causes more scrambling of the sequence and longer throughput times. Note that while the quality checks are randomized, there are certain daily quotas for the different types of vehicles, and at the assembly the quality assurance department even has different quotas for Transporters and Multivans.

A last weak point that relates to the planning process is the **(3.2) measurement of the sequence window reliability with parameter 400 at checkpoint M100** and thus the start of assembly, which reveals little about the possibility of early order picking for JIS components. The measurement of such a large window makes sense for a checkpoint before the ASRS with a target-fill level of 400 vehicles, because the ASRS can then restore a sequence by up to 400 positions. After restoration of the sequence, however, the SWR(400) is of little use. The degree to which the assembly sequence resembles the plan sequence and thus corresponds to the planned smoothing of production, as well as the duration for which JIS components have to be kept in stock cannot be illustrated by such a key figure. Even the instruction for measurement at M100, according to the guidebook of the Volkswagen Group, is to measure the sequence performance [33].

(3.3) Unstable production processes are the main cause for deviations from the plan-sequence. This results in large efforts for material handling and thus increased costs.

Table 18 summarizes all of the identified problems, along with the expected benefit and mitigation cost that were used to focus the problems to be treated in the problem solving approaches of this thesis.

Table 18: Summary of identified Problems

category	ID	problem	expected benefit	expected mitigation cost
information of JIS suppliers	1.1	forecast data for JIS suppliers	high	low
	1.2	lack of knowledge of JIS suppliers		
internal information	2.1	lack of information for distribution department	high	medium
	2.2	type of information for distribution department		
scheduling & sequencing	3.1	special vehicle bodies	high	medium
	3.2	multiple paint layers		
	3.3	throughput times of painting line 1		
	3.4	difference between the target and plan sequence		
product variance	4.1	early order-assignment	high	high
	4.2	early generation of variants using emblems		
production structure	5.1	production structure in painting	very high	very high
	5.2	advance production		
control of vehicle flow	6.1	quality checks of delayed vehicles	medium	medium
	6.2	measurement of SWR(400) at M100		
	6.3	unstable production processes		

Appendix H. Solution Assessment Calculations

Table 19: Calculations for the reduction of T5 JIS supplier stocks at the 3PL

ID	Country	distance to Hannover [km]	volume per part [m³]	parts per container	parts per year	days per year	m³ per year	m³ per day	m³ at 3PL	m³ at 3PL, reduced, safety factor 2	m³ at 3PL, reduced, safety factor 3
1	GER	150	0.96	30	126411	234	4045.2	18	54	23.94	36
	GER	150	1.86875	61	31333	234	959.9	5	15	6.65	10
2	GER	90	2.40625	25	6021	234	579.5	3	9	3.99	6
	GER	90	1.96875	25	9604	234	756.3	4	12	5.32	8
	GER	90	0.972	35	6015	234	167.0	1	3	1.33	2
	GER	90	2.40625	25	25	234	2.4	1	3	1.33	2
3	DEN	450	9.018	5	1665	234	3003.0	13	65	65	65
	DEN	450	3.6072	1	550	234	1984.0	9	45	45	45
4	GER	160	13.464	5	2698	234	7265.2	32	96	42.56	64
	GER	160	5.0184	1	1146	234	5751.1	25	75	33.25	50
5	GER	51	1.4508	152	120331	234	1148.5	5	7.5	7.5	7.5
	GER	51	2.4	6	62566	234	25026.4	107	160.5	160.5	160.5
	GER	51	0.96	27	317153	234	11276.6	49	73.5	73.5	73.5
	GER	51	1.512	9	232150	234	39001.2	167	250.5	250.5	250.5
6	GER	200	0.96	48	278642	234	5572.8	24	72	31.92	48
	GER	200	0.96	43	539407	234	12042.6	52	156	69.16	104
	GER	200	0.96	60	89054	234	1424.9	7	21	9.31	14
	GER	200	0.96	30	89054	234	2849.7	13	39	17.29	26
	GER	200	0.96	18	65481	234	3492.3	15	45	19.95	30
7	SVK	830	2.28	5	7203	234	3284.6	15	120	120	120
	SVK	830	2.04	5	41908	234	17098.5	74	592	592	592
	SVK	830	1.2	8	46492	234	6973.8	30	240	240	240
	SVK	830	2.652	13	65562	234	13374.6	58	464	464	464
8	GER	690	2.52	4	28484	234	17944.9	77	231	102.41	154
9	GER	145	4.8	17	89054	234	25144.7	108	324	143.64	216
	GER	145	4.08	17	37519	234	9004.6	39	117	51.87	78
10	GER	70	4.7	14	49612	234	16655.5	72	108	108	108
	GER	70	3.9	15	28812	234	7491.1	33	49.5	49.5	49.5
11	ESP	2.05	0.96	69	104895	234	1459.4	7	10.5	10.5	10.5
12	GER	180	4.725	12	12520	234	4929.8	22	66	29.26	44
13	GER	55	2.652	13	15000	234	3060.0	14	21	21	21
14	GER	160	2.04	10	42089	234	8586.2	37	111	49.21	74
15	GER	85	0.924	500	139321	234	257.5	2	3	3	3
	GER	85	0.924	250	139321	234	514.9	3	4.5	4.5	4.5
	GER	85	3.23	800	139321	234	562.5	3	4.5	4.5	4.5
	GER	85	6.048	800	139321	234	1053.3	5	7.5	7.5	7.5
16	GER	90	1.0476	18	278642	234	16217.0	70	210	93.1	140
17	CZE	480	0.0336	19	139321	234	246.4	2	10	10	10
Total									**3895.5**	**2971.99**	**3342.5**

Table 20: Cost estimation for implementation of the integration of scheduling and sequencing

	post	item	Sales IT	Sales other	Planning IT	Planning other	Supply IT	Supply other	Production IT	Production other	Distribution IT	Distribution a	subtotals
CAPEX	detailed investigation on required changes	effort [hours]	€ -	€ 16	€ 80	€ 60	€ 16	€ 40	€ -	€ -	€ -	€ -	€ -
		costs [€/h]	€ 117	€ 117	€ 117	€ 117	€ 117	€ 117	€ 117	€ 117	€ 117	€ 117	€ -
		material [€]	€ -	€ -	€ -	€ -	€ -	€ -	€ -	€ -	€ -	€ -	€ -
		safety factor	€ 2	€ 2	€ 2	€ 2	€ 2	€ 2	€ 2	€ 2	€ 2	€ 2	€ -
		subtotal	€ -	€ 2808	€ 14040	€ 10530	€ 2808	€ 7020	€ -	€ -	€ -	€ -	€ 37206
	preparation of implementation	effort [hours]	€ -	€ 40	€ 160	€ 160	€ 40	€ 40	€ -	€ -	€ -	€ -	€ -
		costs [€/h]	€ 117	€ 117	€ 117	€ 117	€ 117	€ 117	€ 117	€ 117	€ 117	€ 117	€ -
		material [€]	€ -	€ -	€ -	€ -	€ -	€ -	€ -	€ -	€ -	€ -	€ -
		safety factor	€ 2	€ 2	€ 2	€ 2	€ 2	€ 2	€ 2	€ 2	€ 2	€ 2	€ -
		subtotal	€ -	€ 7020	€ 28080	€ 28080	€ 7020	€ 7020	€ -	€ -	€ -	€ -	€ 77220
	one-off coaching about new procces	effort [hours]	€ -	€ 40	€ -	€ 12	€ -	€ 160	€ -	€ -	€ -	€ -	€ -
		costs [€/h]	€ 117	€ 117	€ 117	€ 117	€ 117	€ 117	€ 117	€ 117	€ 117	€ 117	€ -
		material [€]	€ -	€ 2000	€ -	€ 200	€ -	€ 5000	€ -	€ -	€ -	€ -	€ -
		safety factor	€ 2	€ 2	€ 2	€ 2	€ 2	€ 2	€ 2	€ 2	€ 2	€ 2	€ -
		subtotal	€ -	€ 10020	€ -	€ 2406	€ -	€ 35580	€ -	€ -	€ -	€ -	€ 48006
	implementation	effort [hours]	€ -	€ 40	€ 200	€ 200	€ 40	€ 120	€ -	€ -	€ -	€ -	€ -
		costs [€/h]	€ 117	€ 117	€ 117	€ 117	€ 117	€ 117	€ 117	€ 117	€ 117	€ 117	€ -
		material [€]	€ -	€ -	€ -	€ -	€ -	€ -	€ -	€ -	€ -	€ -	€ -
		safety factor	€ 2	€ 2	€ 2	€ 2	€ 2	€ 2	€ 2	€ 2	€ 2	€ 2	€ -
		subtotal	€ -	€ 7020	€ 35100	€ 35100	€ 7020	€ 21060	€ -	€ -	€ -	€ -	€ 105300
	documentation	effort [hours]	€ -	€ 40	€ 40	€ 40	€ 40	€ 40	€ -	€ -	€ -	€ -	€ -
		costs [€/h]	€ 117	€ 117	€ 117	€ 117	€ 117	€ 117	€ 117	€ 117	€ 117	€ 117	€ -
		material [€]	€ -	€ 1000	€ 1000	€ 1000	€ 1000	€ 1000	€ -	€ -	€ -	€ -	€ -
		safety factor	€ 2	€ 2	€ 2	€ 2	€ 2	€ 2	€ 2	€ 2	€ 2	€ 2	€ -
		subtotal	€ -	€ 8520	€ 8520	€ 8520	€ 8520	€ 8520	€ -	€ -	€ -	€ -	€ 42600
		subtotals	**€ -**	**€ 35388**	**€ 85740**	**€ 84636**	**€ 25368**	**€ 79200**	**€ -**	**€ -**	**€ -**	**€ -**	**€ 310332**
OPEX	maintenance	effort [hours]	€ -	€ -	€ 40	€ -	€ 40	€ -	€ -	€ -	€ -	€ -	€ -
		costs [€/h]	€ 117	€ 117	€ 117	€ 117	€ 117	€ 117	€ 117	€ 117	€ 117	€ 117	€ -
		material [€]	€ -	€ -	€ -	€ -	€ -	€ -	€ -	€ -	€ -	€ -	€ -
		safety factor	€ 2	€ 2	€ 2	€ 2	€ 2	€ 2	€ 2	€ 2	€ 2	€ 2	€ -
		subtotal	€ -	€ -	€ 7020	€ -	€ 7020	€ -	€ -	€ -	€ -	€ -	€ 14040
		subtotals	**€ -**	**€ -**	**€ 7020**	**€ -**	**€ 7020**	**€ -**	**€ -**	**€ -**	**€ -**	**€ -**	**€ 14040**

Appendix I. Boxplots

Table 21: Summary of sequence deviation values for T5 with different features at the different counting points between 04-03-2013 and 19-04-2013

feature	check-point	avg. min	mean median	avg. max	avg. vehicles per day	avg. percentage
all T5	R150	-261	-7	2394	562.2	100.0%
T5, no NSR/DLP/PL1		-158	-7	2302	498.4	88.7%
T5 with NSR		-113	10	254	47.2	8.4%
T5 with DLP		-10	-3	114	5.1	0.9%
T5 on PL1		-7	-6	13	14.6	2.1%
all T5	R900	-253	-29	2686	558.4	100.0%
T5, no NSR/DLP/PL1		-247	-31	2255	476.3	85.2%
T5 with NSR		-27	97	836	47.0	8.5%
T5 with DLP		-45	-25	154	5.1	0.9%
T5 on PL1		-68	-32	138	30.8	5.5%
all T5, sequence shift NSR		-271	-23	2659	47.0 | 558.4	8.5% | 100%
all T5	LH00	-394	-103	5624	560.5	100.0%
T5, no NSR/DLP/PL1		-391	-119	4492	459.3	81.9%
T5 with DLP		65	221	688	4.8	0.9%
T5 on PL1		64	291	1769	51.0	9.0%
all T5, sequence-shift DLP/PL1/NSR		-395	-80	5577	101.2 | 560.5	18.1% | 100%
all T5, sequence shift DLP/NSR		-405	-99	5613	50.2 | 560.5	9.0% | 100%
all T5, sequence shift DLP		-393	-102	5625	4.8 | 560.5	0.9% | 100%
all T5, sequence shift NSR		-408	-100	5612	45.4 | 560.5	8.2% | 100%
all T5, sequence shift PL1		-390	-84	5589	51.0 | 560.5	9.0% | 100%
all T5	M100	-436	-72	5145	556.7	100.0%
T5, no NSR/DLP/PL1		-431	-82	4365	456.2	82.0%

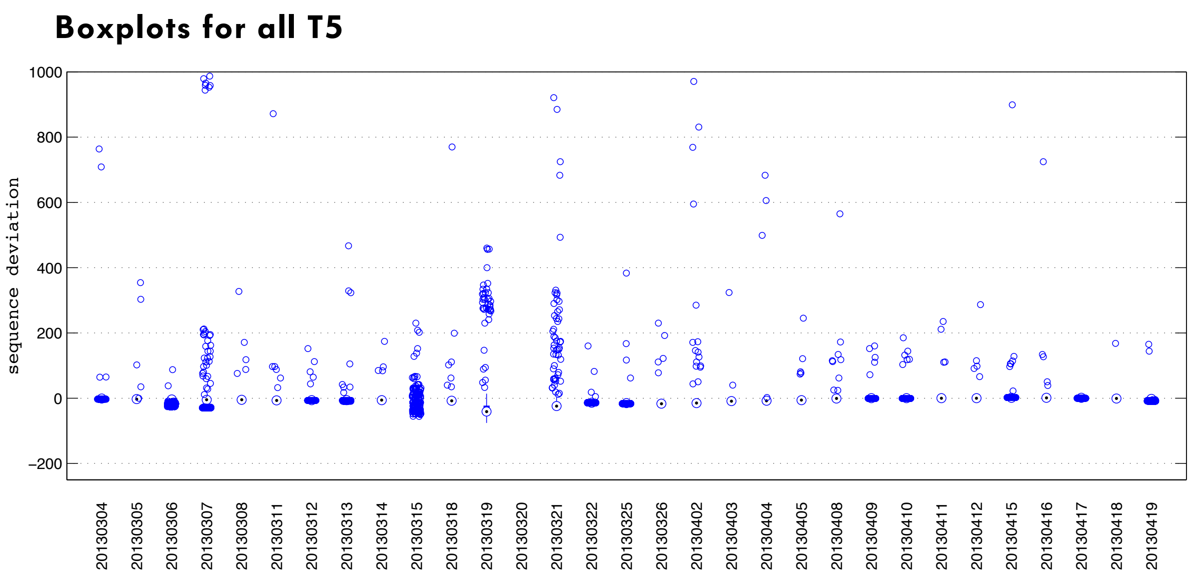


Figure 56: of the sequence deviations for all T5 at R150

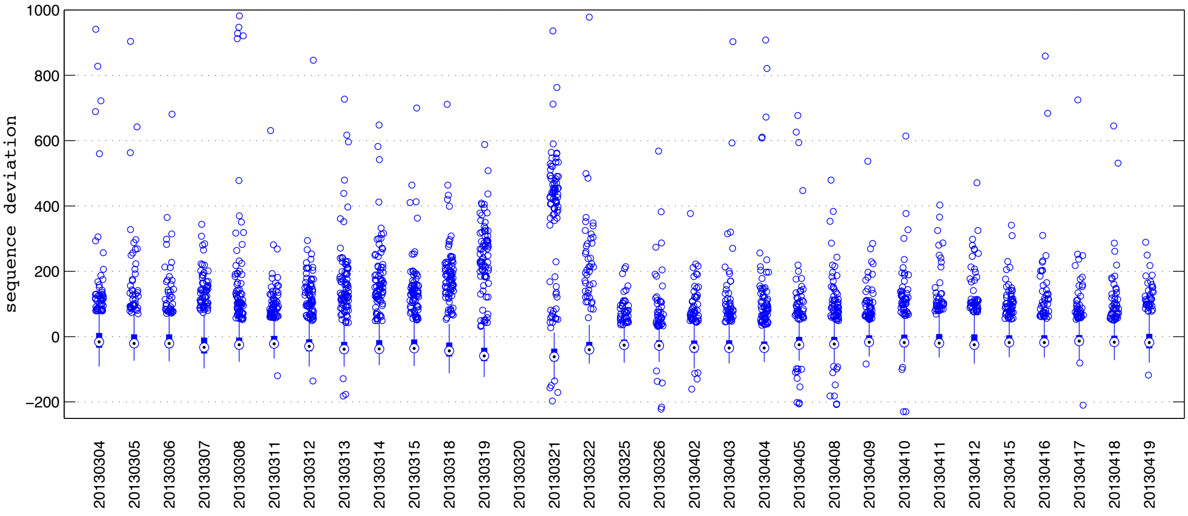


Figure 57: Boxplot of the sequence deviations for all T5 at R900

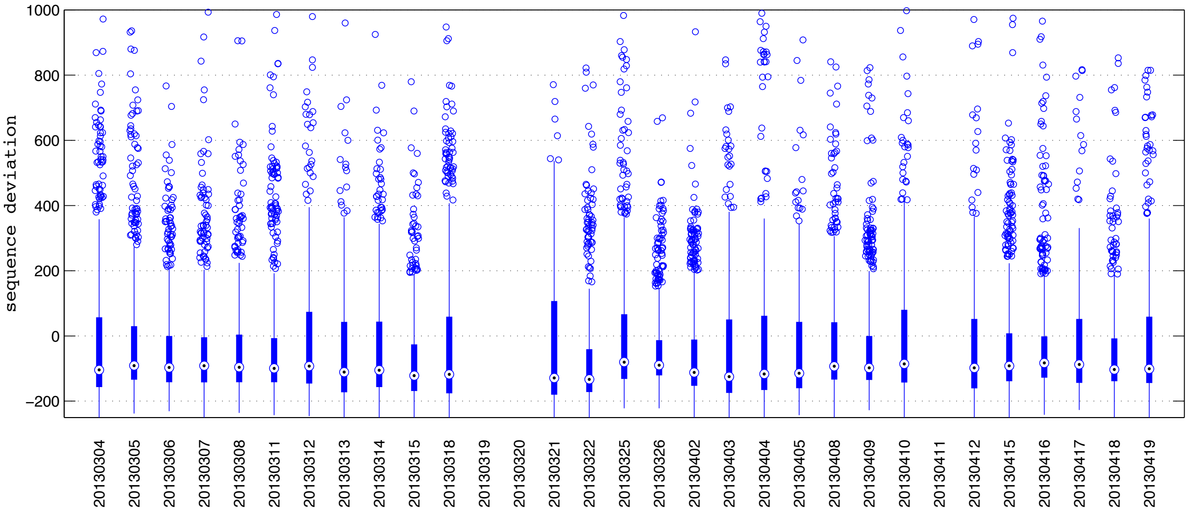


Figure 58: Boxplot of the sequence deviations for all T5 at LH00

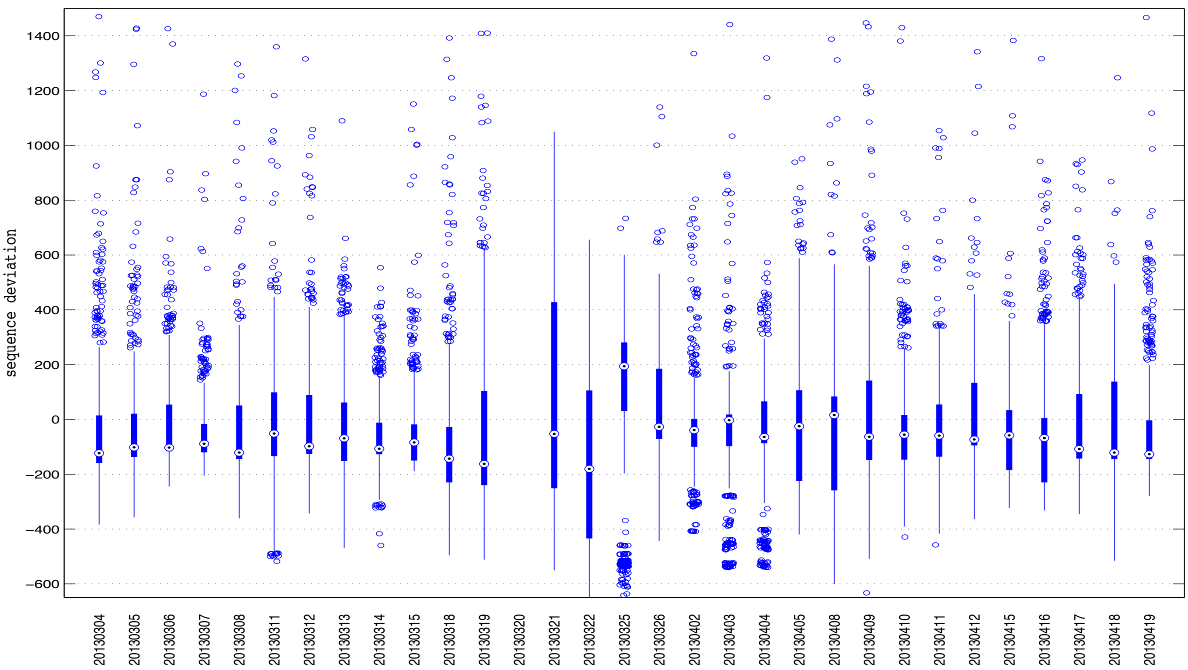


Figure 59: Boxplot of the sequence deviations for all T5 at M100

Boxplots for T5 with Non-Standard Roof

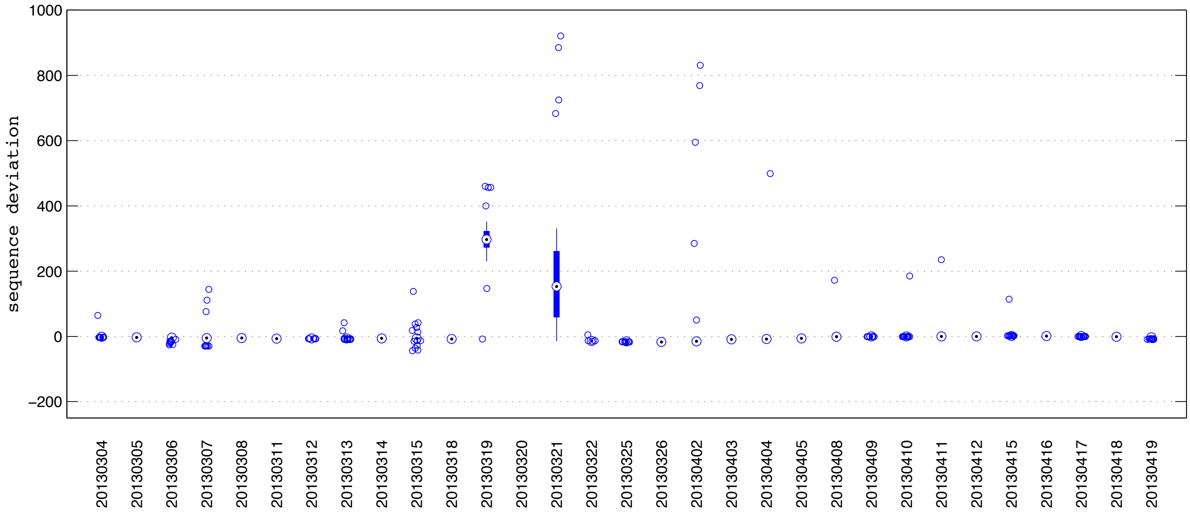


Figure 60: Boxplot of the sequence deviations for T5 with NSR at R150

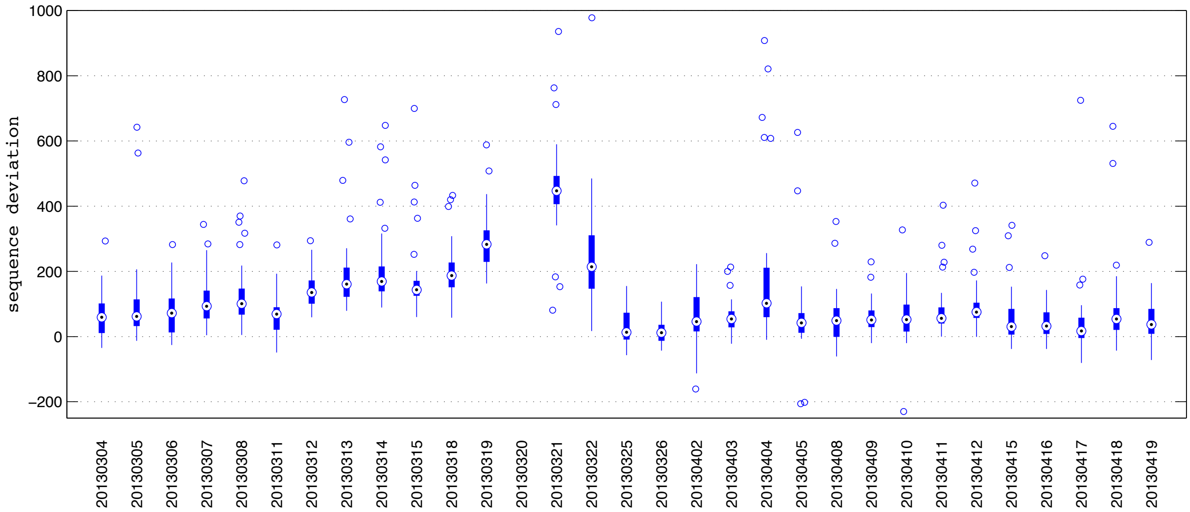


Figure 61: Boxplot of the sequence deviations for T5 with NSR at R900

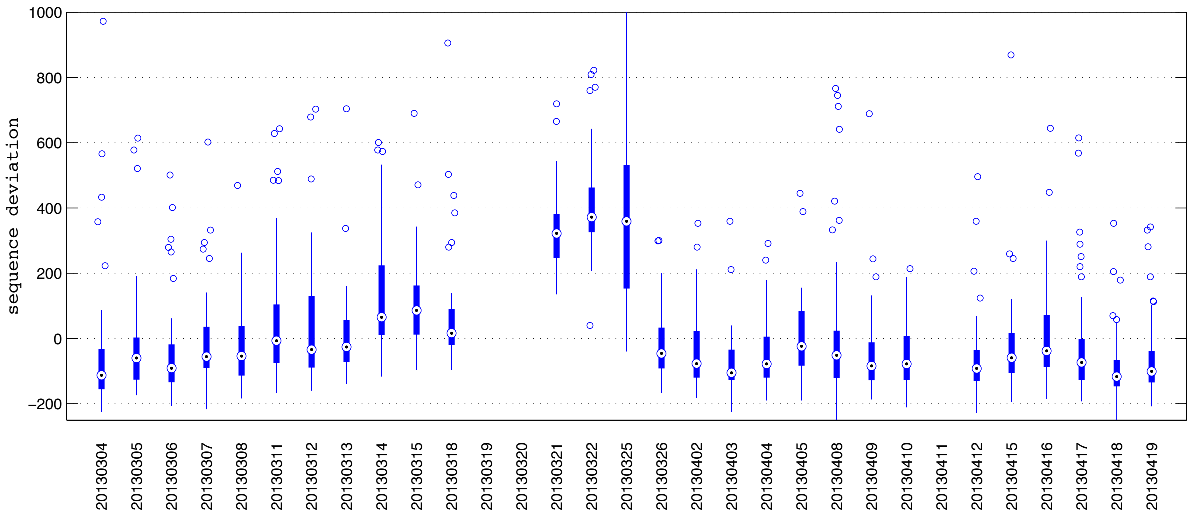


Figure 62: Boxplot of the sequence deviations for T5 with NSR at LH00

Boxplots for T5 with DLP

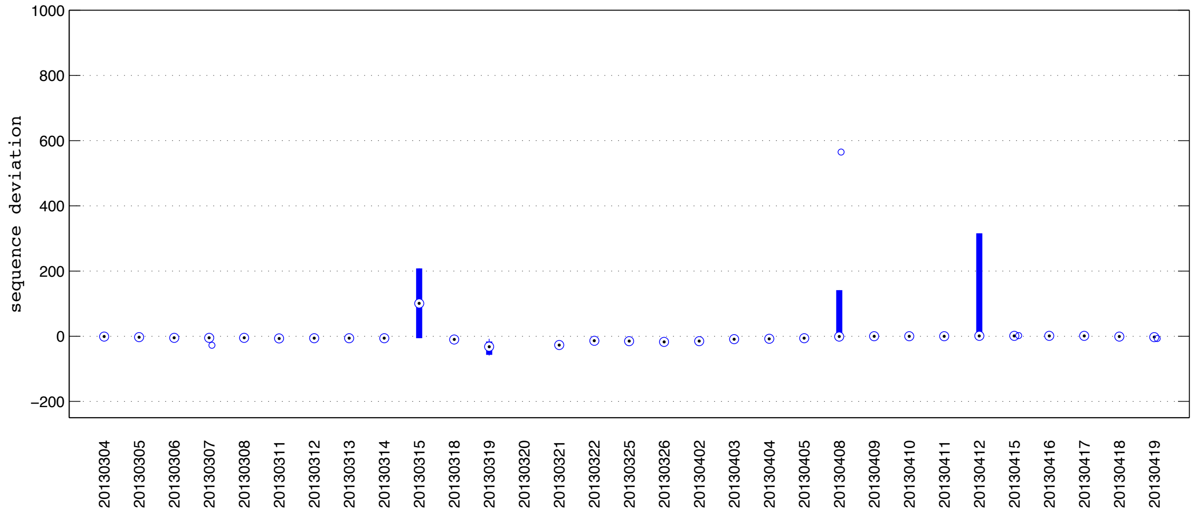


Figure 63: Boxplot of the sequence deviations for T5 with DLP at R150

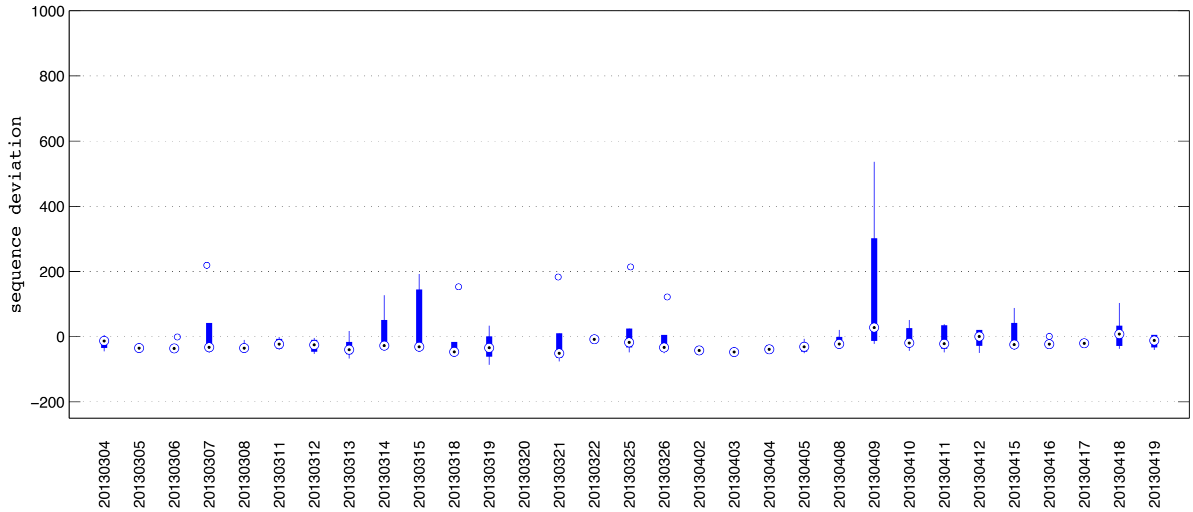


Figure 64: Boxplot of the sequence deviations for T5 with DLP at R900

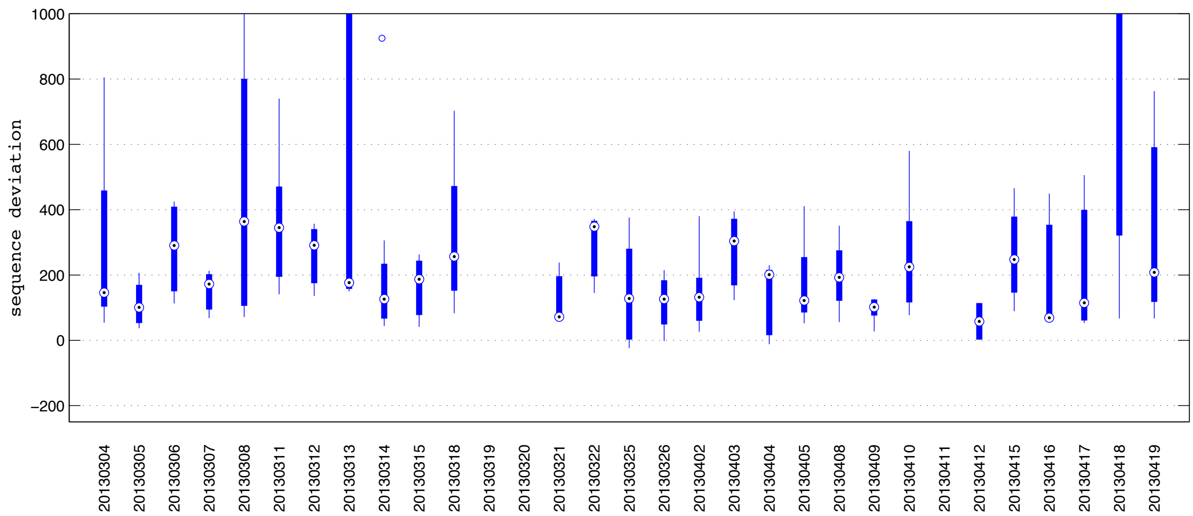


Figure 65: Boxplot of the sequence deviations for T5 with DLP at LH00

Boxplots for T5 on PL1

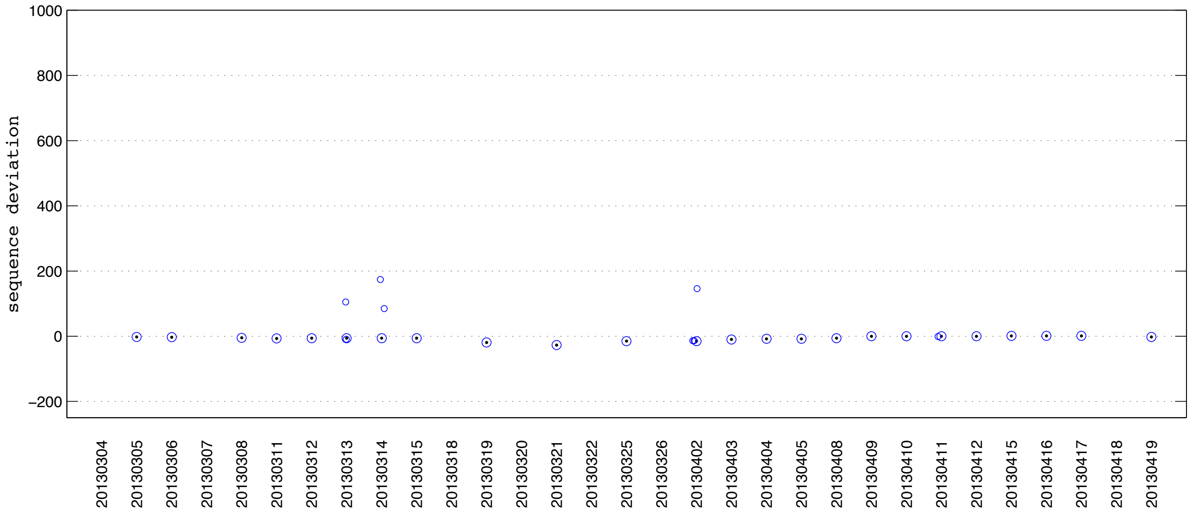


Figure 66: Boxplot of the sequence deviations for T5 painted on PL1 at R150

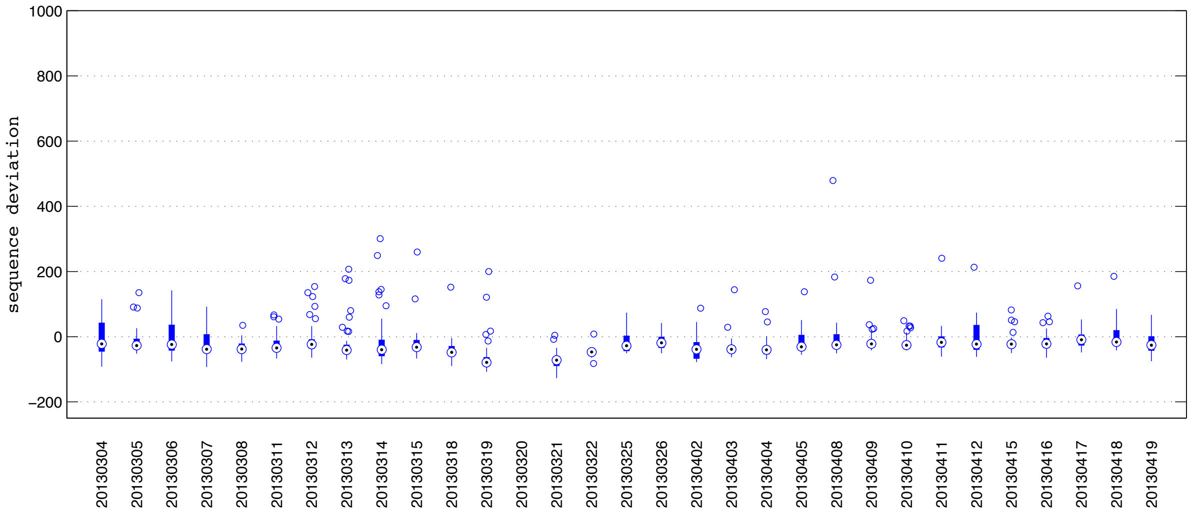


Figure 67: Boxplot of the sequence deviations for T5 painted on PL1at R900

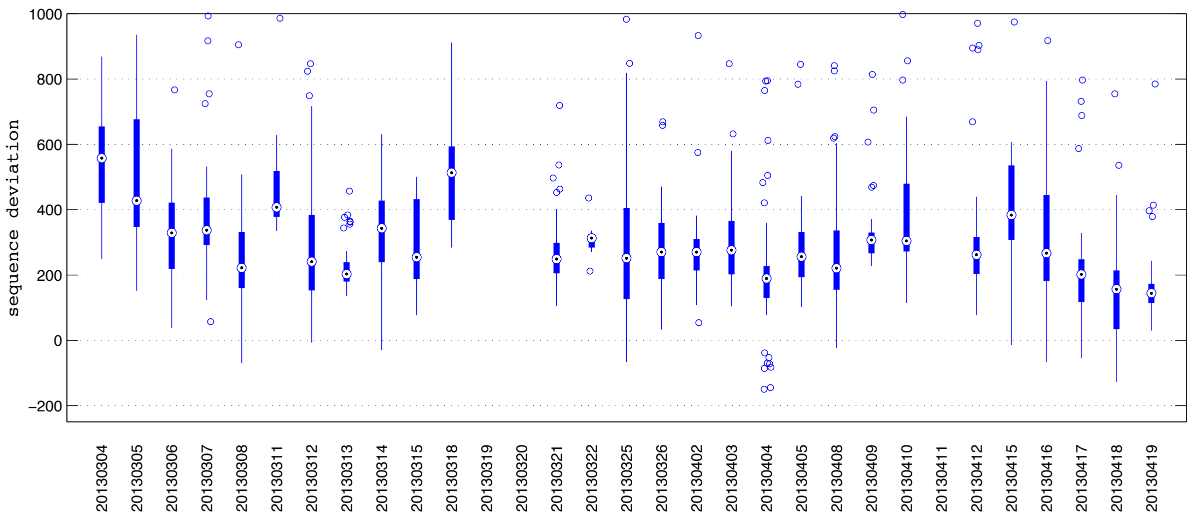


Figure 68: Boxplot of the sequence deviations for T5 painted on PL 1 at LH00

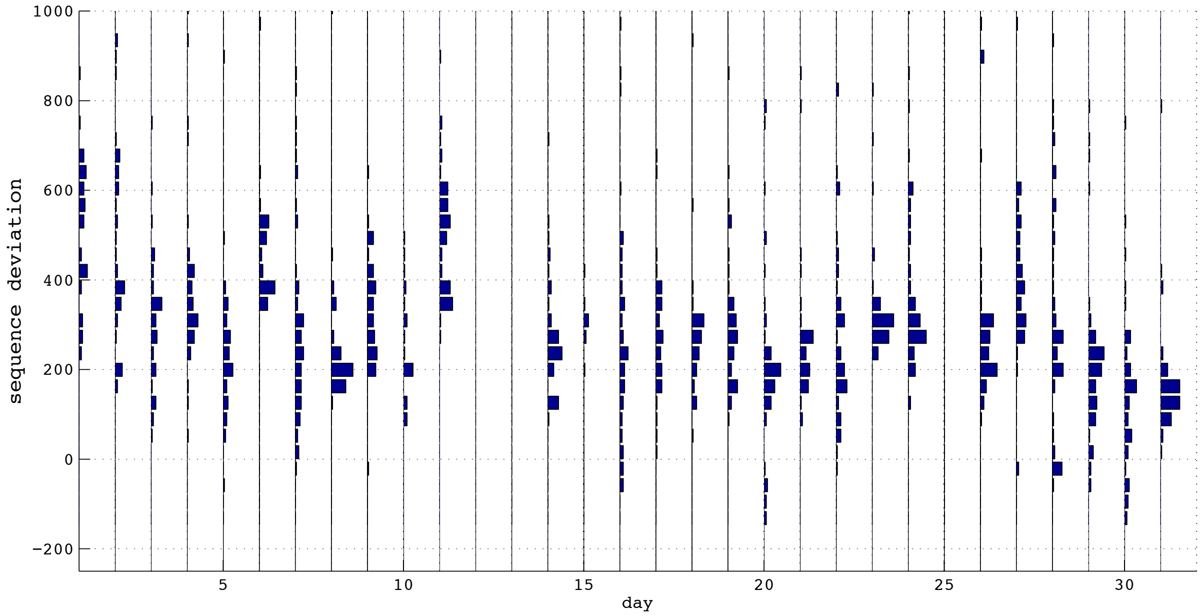


Figure 69: Boxplot alternative - vertical sequence deviation histogram for T5 that were painted on PL 1 at LH00

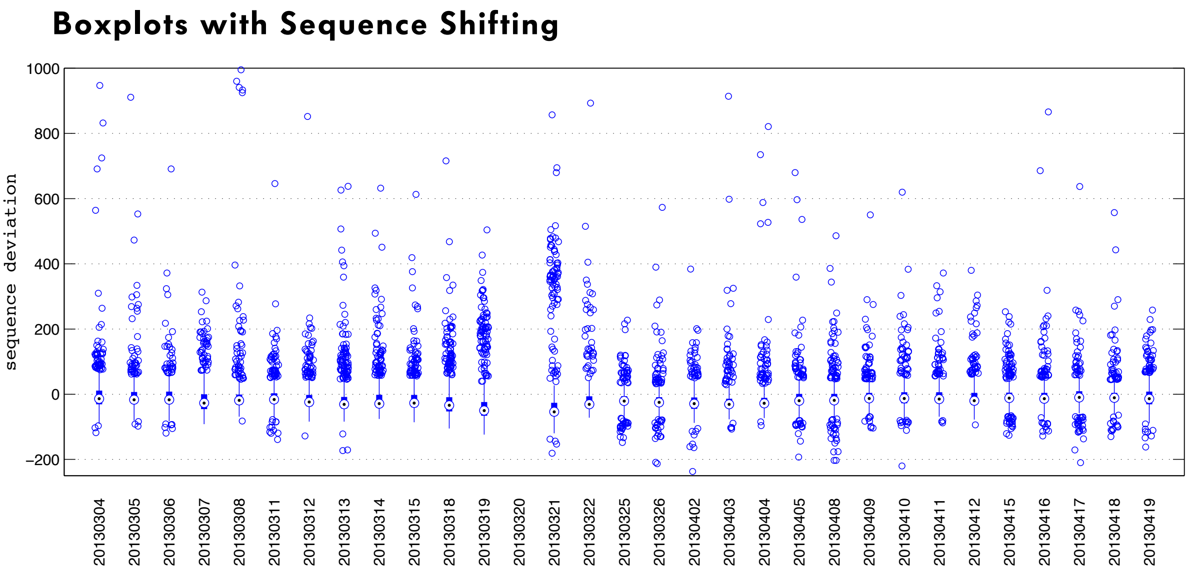


Figure 70: Boxplot for the new situation at R900, after the introduction of time-shift (for T5 with NSR (-97))

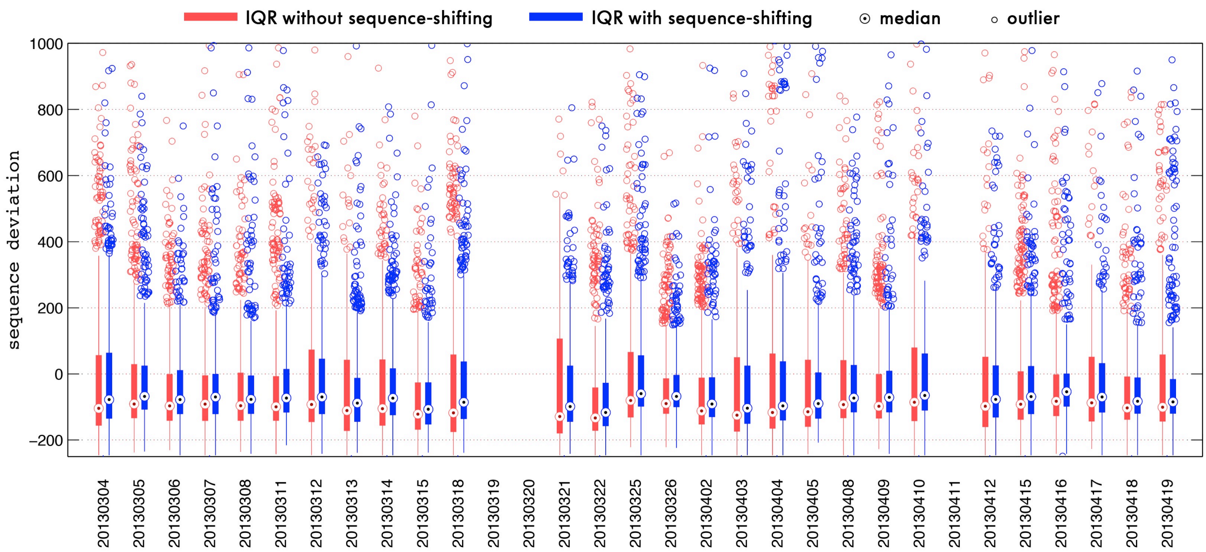


Figure 71: Boxplot comparing situation at LH00 before (red) and after (blue) the introduction of time-shift (for T5 with NSR (-97), DLP (-221), or painted on PL1 (-291))

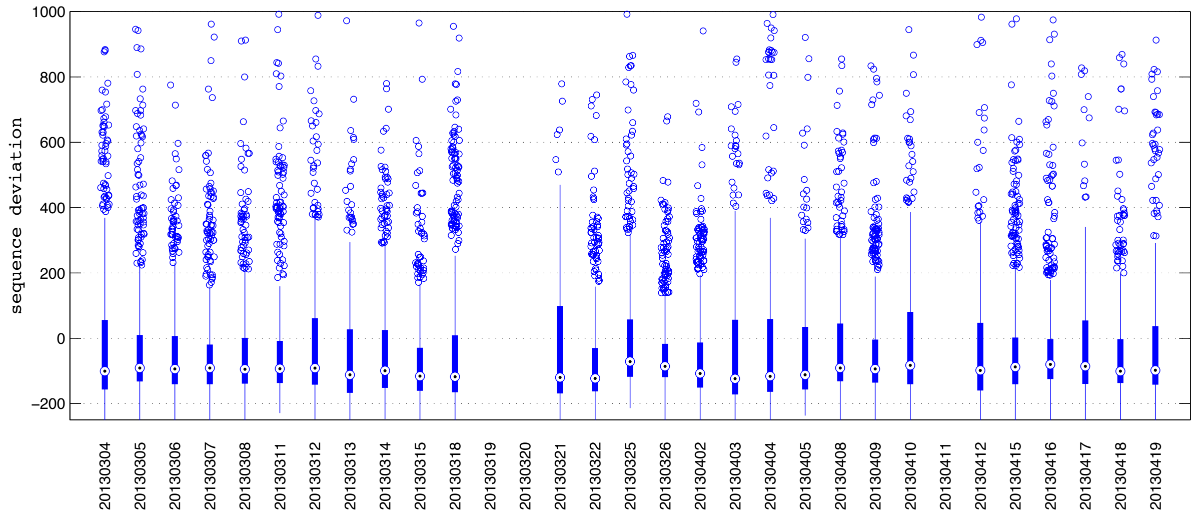


Figure 72: Boxplot for the new situation at LH00, after the introduction of time-shift (for T5 with NSR (-97), DLP (-221))

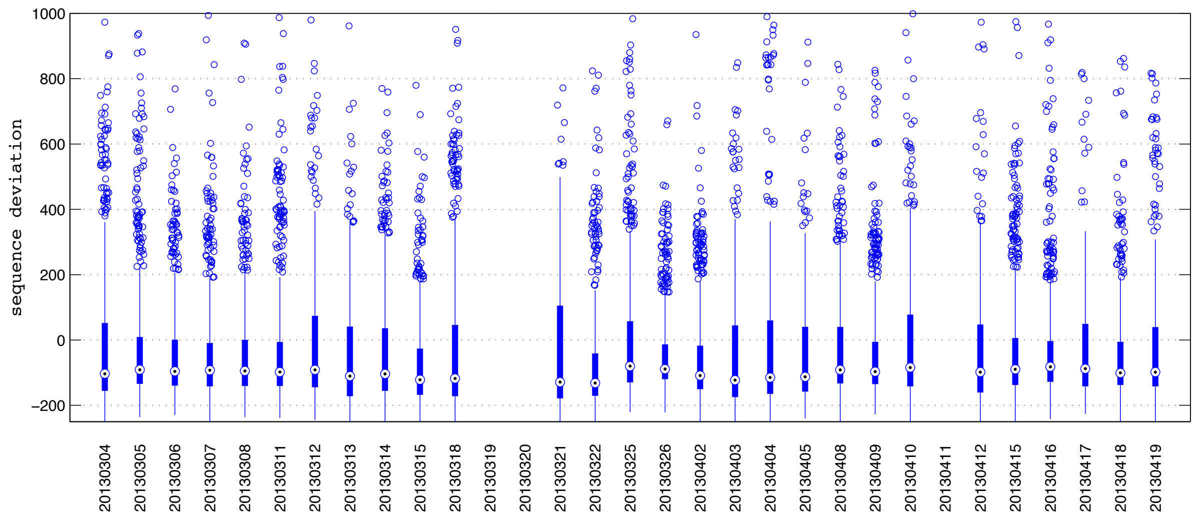


Figure 73: Boxplot for the new situation at LH00, after the introduction of time-shift (for T5 with DLP (-221))

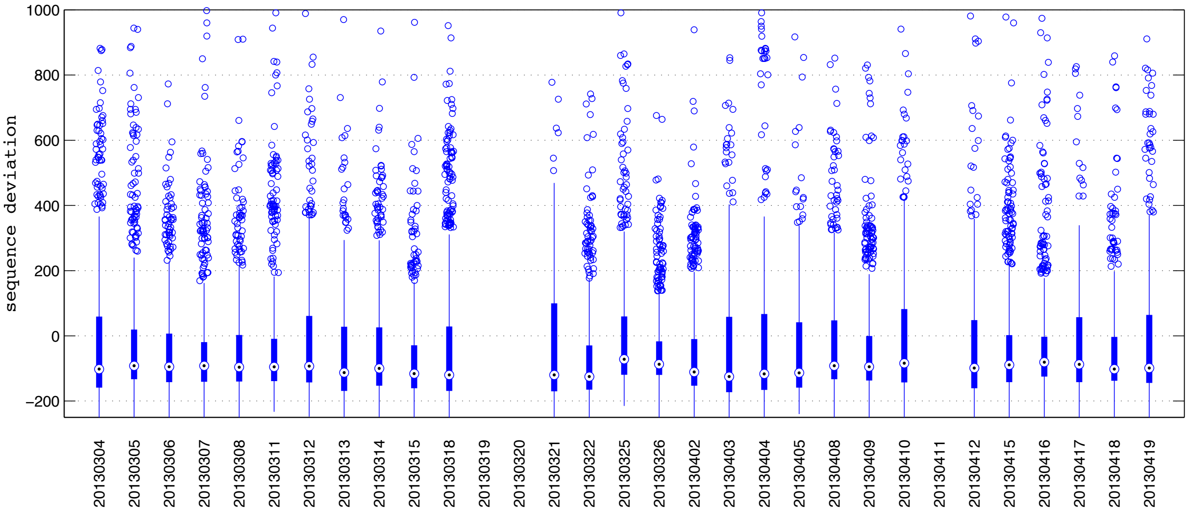


Figure 74: Boxplot for the new situation at LH00, after the introduction of time-shift (for T5 with NSR (-97))

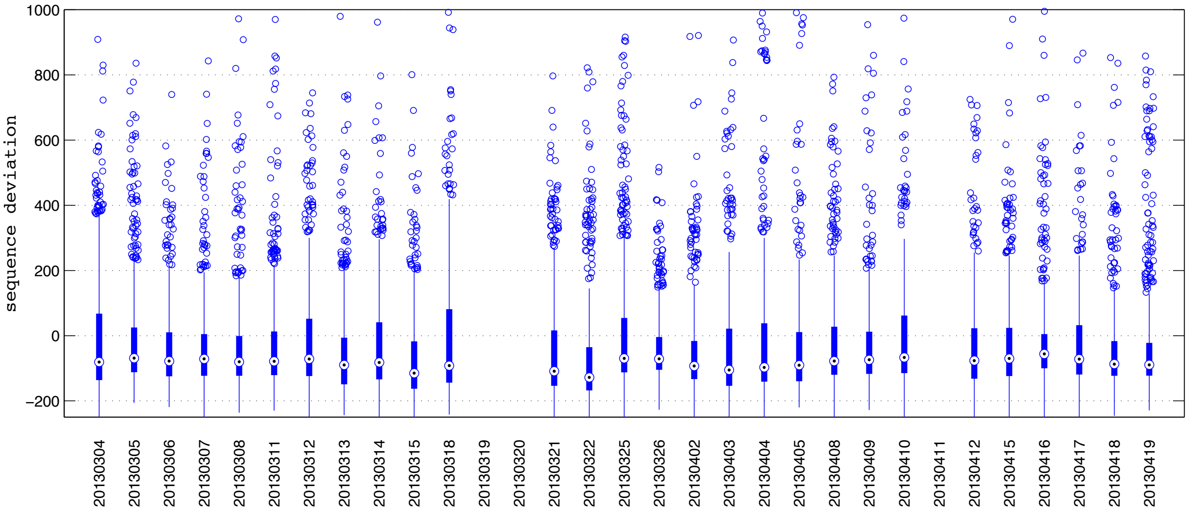


Figure 75: Boxplot for the new situation at LH00, after the introduction of time-shift (for T5 painted on PL1 (-291))

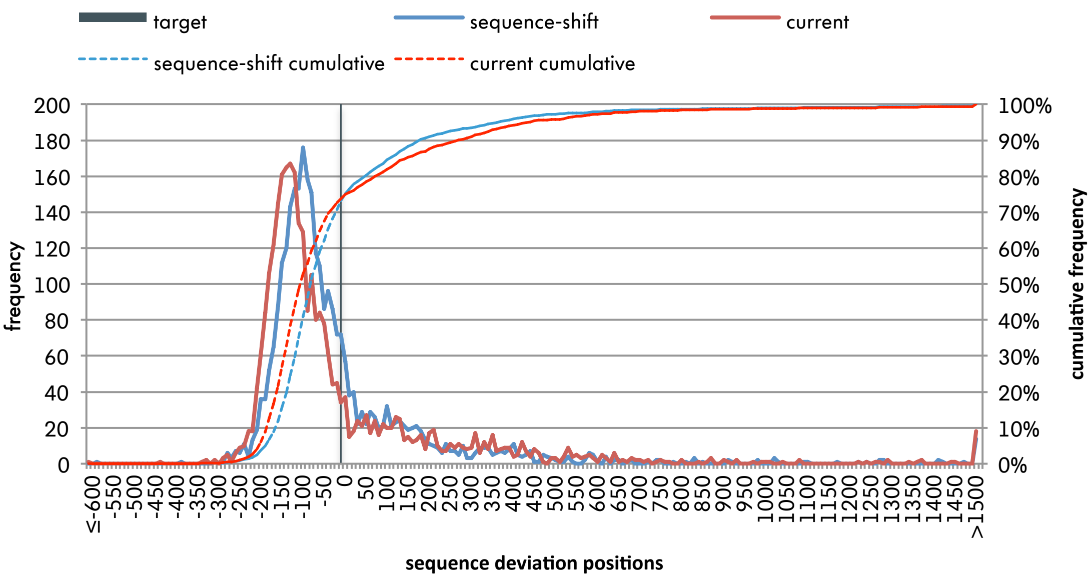


Figure 76: Sequence deviation histogram for T5 at LH00 in week 10-2013 before (red) and after (blue) the introduction of sequence shifting

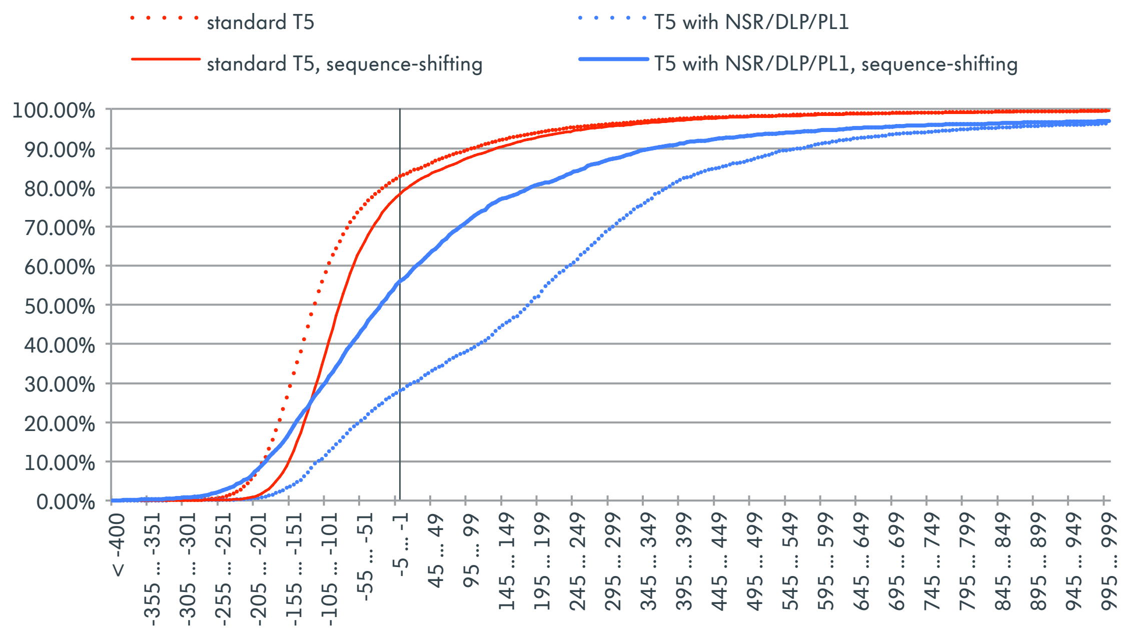


Figure 77: Cumulative sequence deviations at LH00 before and after sequence-shifting

Appendix J. Key Figure Values for Sequence-Shifting

Table 22: Key figure values per sequence-shifting feature (04-03-2013 - 19-04-2013)

key figure	checkpoint	current situation	sequence-shift DLP/PL1/NSR	change	sequence-shift NSR only	change	sequence-shift DLP only	change	sequence-shift PL1 only	change
SWR(0) = SQP	R150	99.6%	-	-	-	-	-	-	-	-
SWR(10)		98.1%	-	-	-	-	-	-	-	-
SWR(400)		94.6%	-	-	-	-	-	-	-	-
standard deviation		149	-	-	-	-	-	-	-	-
SWR(0) = SQP	R900	76.2%	-	-	75.0%	-1.2%	-	-	-	-
SWR(10)		80.5%	-	-	80.8%	0.3%	-	-	-	-
SWR(400)		99.0%	-	-	99.3%	0.3%	-	-	-	-
standard deviation		187	-	-	181	-6	-	-	-	-
SWR(0) = SQP	LH00	72.5%	73.7%	1.2%	72.8%	0.3%	72.8%	0.3%	72.5%	0.0%
SWR(10)		73.4%	75.3%	1.9%	74.0%	0.6%	73.7%	0.3%	74.0%	0.6%
SWR(400)		94.8%	96.1%	1.3%	94.8%	0.0%	94.8%	0.0%	95.6%	0.8%
standard deviation		374	348	- 26	372	-2	373	-1	355	-19
SWR(0) = SQP	M100	66.0%	-	-	-	-	-	-	-	-
SWR(10)		67.7%	-	-	-	-	-	-	-	-
SWR(400)		93.6%	-	-	-	-	-	-	-	-
standard deviation		378	-	-	-	-	-	-	-	-

Appendix K. Detailed Table of Identified Problems

category	ID	weak point	symptom	cause	approach	expectations	auxiliary procurement costs	internal area	CAPEX	OPEX	operative logistic times	assessment of measure
information of suppliers	1.1	forecast data for JIS suppliers	suppliers are unable to plan regardless of receiving forecast data and starting notice at body construction	suppliers only receive ZP8 data	transfer delivery/shipping data to suppliers rather than ZP8 data	greater certainty in planning, thus greater security of supply	↘	→	→	→	→	deviation of actual dates from planned dates
	1.2	point of JIS preview data transfer to suppliers	JIS suppliers have little time to plan their production according to the assembly sequence	suppliers receive a sequence preview at R150	shift point of data transfer from R150 to A600	marginally changing sequence between A600 and R150, but 4 work days of additional planning time for JIS suppliers and thus optimized production costs	↘	↘	→	→	→	sequence scrambling between A600 and R150 and the production costs of JIS parts
internal information	2.1	lack of information for distribution department	distribution department cannot plan ahead	distribution only receives SONATA3 data and ZP8 notice, but no vehicle-specific data	status reports for distribution department, incl. relevant data (e.g. dimensions, weight, destination, currently estimated completion, blocking/release)	reduced storage times (especially for vehicles to be sent via trucks), as well as a reduction of costs for storage due to increased ability for planning	→	↘	↗	↘	→	analysis of average storage times and shipping costs
	2.2	type of information for distribution department	BUS vehicles are unavailable, but distribution is charged for time in BUS	Distribution receives ZP8 notice, despite the fact that the vehicle has to be processes in the BUS	add extra counting point for final release for distribution	increased ability to plan, as well as charging the responsible section for increased throughput times	→	↘	↗	↗	→	analysis of average storage times
scheduling & sequencing	3.1	special vehicle bodies	large variance in processing times depending on the variant	no feature-based calculation and scheduling in body construction	SONATA3-consideration of statistical analyses of processing times for specific features (like high roofs) that are processed aside the assembly line or automation of advance production for specific features	less deviations from the sequence in body construction	↘	↘	↗	↗	→	SQD histograms (incl. body types), throughput times of the different sections
	3.2	multiple paint layers	specific colors are painted twice and scramble the sequence	multiple layers of paint for specific colors are not considered in planning	consideration of additionally planned paint layers in scheduling and sequencing	less deviations from the sequence at entering the ASRS	↘	↘	↗	↗	→	SQD histograms (incl. colors), throughput times of the different sections
	3.3	lack of block building	the sequence changes from SONATA3 to FIS DISPO II	wheelbase blocks are not considered in SONATA3	consider wheelbase in SONATA planning	less deviations of the sequences in the different sections	↘	↘	↗	↗	→	SQD histograms
	3.4	throughput times of painting line (PL) 1	large unplanned variance of throughput times on different painting lines	throughput time PL 1 is larger than for PL 3 and PL 4	plan processing on specific PL and take longer throughput time into account for PL 1	less deviations from the sequence at entering the ASRS	↘	→	→	↗	→	SQD histograms (incl. colors), throughput times of the different sections
variance	4.1	early order-assignment	single order are delayed intensely if (partial) scrapping is necessary	order-assignment occurs in the beginning of body construction	investigate bestselling bodies and the ability to shift the order-assignment point to assembly (M100)	reduced production skewness length due to less intense delays	↘	↘	↗	↗	→	production skewness length and volume
	4.2	early generation of variants using emblems	large variance in identical car bodies due to e.g. emblems even before entry in assembly	emblems (TDI, 4Motion, etc.) and interior foils are applied in painting	shift application of emblems to the beginning of assembly	less variance before assembly, greater ability for late order assignment, better sequence performance --> only useful if combined with late order assignment	↘	↗	↗	→	↗	SQD histograms
structure	5.1	production structure in painting	large buffers and distribution of models necessary to fully utilize the downstream processes	multiple sequences move over one line	restructure the production structure in painting to have separate lines per product	less interdependence between the different sequences, reduced impact of disturbances for one product	↘	↗	↗	↗	→	SQD histograms
	5.2	advance production	orders planned for the following day are produced in advance due to overproduction, which leads to parts for production orders being unavailable	section-specific optimization of the assembly process	temporarily stop production when target production value is reached	higher day reliability	↘	↗	→	↗	→	day reliability report
control of vehicle flow	6.1	quality checks of delayed vehicles	late vehicles are used for random sampling and are delayed even more	random sampling does not consider due dates (CHECK DEPENDENCE)	use vehicles with little or no delay for random sampling	less skew or kurtosis of throughput time distribution	↘	→	→	↗	→	SQD histograms, throughput times of the different sections
	6.2	measuring SWR(400) at M100	assessment of large sequence window reliability reveals little about the possibility of early order picking for JIS parts	the sequence window is too large	measuring the SP rather than SWR(400)	problems become visible at an earlier stage						
	6.3	unstable production processes	only 1,4% of vehicles deviate less than 10 slots from the plan sequence at M100 (W6/2013)	instability of production processes with inconsistent throughput times of vehicles								

Appendix L. Key Figures of Just-in-Sequence Production

group	key figure	abbreviation	measurement	function	source
maintenance of the sequence	sequence quality of the pearl chain	RFG_{PK}	percentage of vehicles not exactly in sequence and number of gaps in sequence	determination of additional handling	Weyer
maintenance of the sequence	position bandwidth quality of the pearl chain	PBG_{PK}	extent of the largest deviation from the sequence	determination of resequencing quantity	Weyer
due-date wise performance	target due date quality of the pearl chain	STG_{PK}	precentage of vehicles produced within specific target period	evaluation of suitability for sourcing method	Weyer
due-date wise performance	plan due date quality of the pearl chain	PTG_{PK}	precentage of vehicles produced within specific plan period	evaluation of suitability for sourcing method	Weyer
due-date wise performance	production delivery reliability	PLT	percentage of vehicles completed on due date	evaluation of production reliability	Weyer
content-wise performance	model mix quality of the pearl chain (equal distribution)	$MmixG_{PK}$ (equal distribution)	monetary assessment of the violations of the restrictions in sequencing	evaluation of production smoothing and leveling	Weyer
content-wise performance	model mix quality of the pearl chain (block)	$MmixG_{PK}$ (block)	average size of production blocks	evaluation of changeover frequency	Weyer
due-date wise performance	sequence performance	PKG /SQP	percentage of vehicles not delayed or missing in the sequence (historical)	entire process' (up to measuring point) adherence to the sequence	Volkswagen
due-date wise performance	sequence window reliability	PFT(w) / SWR(w)	percentage of vehicles not delayed by more than w elements or missing in the sequence (historical)	entire process' (up to measuring point) adherence to the sequence; measure of ability to reinstate plan sequence using ASRS	Volkswagen
due-date wise performance	sequence adherence	RFE	percentage of vehicles not delayed in sequence	average resequencing efforts; average frequency of scrambling	Meißner
maintenance of the sequence; due date-wise performanceof the sequence	sequence backlog / cumulated backlog	RR	current number of late vehicles after considered element	sizing of parts buffers; preview of delays	Meißner / Volkswagen
maintenance of the sequence	section's sequence deviation from input	RFA_{rel}	difference of one vehicle's input (section) and actual position in the sequence	identification of scrambling development	Meißner
maintenance of the sequence; due date-wise performance of the sequence	entire process' sequence deviation from plan sequence	RFA_{abs} / SQA / SQD	difference of one vehicle's planned and actual position in the sequence	identification of scrambling development and intensity; optimized control of body resequencing buffers is possible; backlog in term of cycles	Meißner / Volkswagen
due-date wise performance	average absolute deviation	$\overline{(RFA_{rel/abs})}$	average modulus of RFA_{rel} / RFA_{abs} (measured against mean, mode, or median)	identification of scrambling development and intensity; measuring average scrambling; sizing ASRS;	Meißner
due-date wise performance	sequence quality	RFQ	ratio of orders without sequence deviations and target work in process	evaluation of scrambling intensity per section	Meißner
maintenance of the sequence	first in first out reliability	FIFO reliability	percentage of vehicles not delayed or missing in the input sequence (current)	section's adherence to the actual input sequence	Meißner
maintenance of the sequence	first in system first out reliability	FISFO reliability	percentage of vehicles not delayed or missing in the plan-sequence (current)	entire process' adherence to the plan sequence	Meißner