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Resource Planning in the Rail-Bound Logistics

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German Summary

Ressourceneinsatzplanung in der schienengebundenen Logistik

Mit einer Gesamttransportleistung von mehr als 420 Billionen Nettotonnenkilometern nimmt der Schienengüterverkehrssekttor eine Schlüsselrolle in der Europäischen Logistik ein. Hingegen existiert im Hinblick auf die Planung und Steuerung des zugrundeliegenden Auftragsabwicklungsprozesses ein beträchtliches Optimierungspotential. Dieser Sachverhalt ist insbesondere auf das Fehlen von wissenschaftlichen Ansätzen zurückzuführen. Um jedoch die prognostizierte Zunahme der Transportmengen weiterhin handhaben zu können und dem Konkurrenzdruck durch die straßengebundene Logistik standhalten zu können muss diesem Rückstand unbedingt entgegengewirkt werden. Vor dem Hintergrund der in der klassischen (physischen) Produktion bereits existierenden best-practice Prozessbeschreibungen, war es das übergeordnete Ziel dieser Arbeit ein auf produktionsbezogenen Methoden, Systemen und Instrumenten basierendes Referenzprozessmodell für den obigen Auftragsabwicklungsprozess zu entwickeln. Zur Erreichung dieser Zielvorgabe bedurfte es zudem einer Transformation der schienengebundenen Logistik in ein klassisches Produktionssystem, um eine direkte Übertrag- und Anwendbarkeit des Modells sicherzustellen. Für die Validierung der zugrundeliegenden Transformation und des Models wurde der Rumänische Schienenverkehrsdienstleister DB Schenker Rail Romania im Rahmen einer Fallstudie in die Arbeit integriert.

Um eine konsistente Vorgehensweise sicherzustellen, wurde zu allererst ein Vorgehensmodell (auch Meta-Referenzprozessmodell) eingeführt. Im Anschluss daran wurde die exakte Definition des Begriffs *Referenzprozessmodells* hergeleitet welche jene Modelle als Schablonen oder Blaupausen beschreibt, deren Anwendung in verschiedensten Industrien die Verbesserung oder Entwicklung von Prozessen zum Ziel hat. In Vorbereitung auf die spätere Entwicklung des Modells schloss der erste Teil mit einer Vorstellung potentiell geeigneter Quellen prozessororientierter Produktionsliteratur ab.

In weiterer Vorbereitung auf die Entwicklung des Modells wurden sodann zwei wichtige Schritte durchgeführt. Im ersten Schritt wurde der Auftragsabwicklungsprozess des klassischen Produktionssektors beschrieben, um eine Grundlage für die übergeordnete Struktur des Referenzprozessmodells zu schaffen und zu eruieren welche Elemente die Kernbestandteile des zu entwickelnden Modells darstellen sollten. Während sich von der kommerziellen Perspektive aus die Auftragsannahme als relevant darstellte, konnten von der technischen Perspektive aus die Planung des Hauptproduktionsprogramms, die

Materialbedarfsplanung, die Ressourceneinsatzplanung, die Feinplanung, die Initiierung der Produktion und das Produktionsmonitoring als Hauptbestandteile identifiziert werden. Diese Elemente beschreiben (in derselben Reihenfolge) auch die Struktur (Architektur) des Prozessflusses im Modell.

Im zweiten Schritt wurde zudem eine Typologie von Produktions- bzw. Auftragsabwicklungssystemen vorgestellt. Basierend darauf können verschiedene Produktionssysteme bzw. deren Auftragsabwicklungsprozess anhand von drei übergeordneter Kategorien klassifiziert werden. Diese Kategorien sind: Ausbringungsbezogene Kriterien, prozessbezogene Kriterien und einsatzbezogene Kriterien. Die Einführung dieser Typologie erfolgte mit dem Ziel ein Werkzeug für die anschließende Transformation bereitzustellen.

Im Zuge der Transformation selbst wurde zunächst der Schienenverkehrssektor inklusiver seiner Zukunftsperspektive vorgestellt. Weiterhin wurden daraufhin das System der schienengebundenen Logistik und die darin vorkommenden Auftragstypen analysiert, um sodann System und Aufträge mit Hilfe der obigen Typologie in die klassische Produktionsterminologie zu überführen.

Der darauffolgende Teil der Arbeit beinhaltete nun die tatsächliche Entwicklung des Modells. Basierend auf einem top-down Ansatz wurde zunächst die erste Ebene des Modells skizziert. Dabei basiert die Architektur auf einzelnen miteinander in Verbindung stehenden Modulen welche jeweils einen abgrenzbaren Prozess der Auftragsabwicklung enthalten. Die Identifizierung dieser Module erfolgte durch die matrixartige Kombination der existierenden Auftragstypen mit den elementaren Funktionen des Auftragsabwicklungsprozesses (s. oben). Unterhalb dieser Ebene konnten sodann die Prozessbeschreibungen innerhalb der einzelnen Module ausgestaltet werden. Zur Illustration der Prozesse und Ergänzung der textuellen Beschreibungen wurde die Modellierungstechnik der Ereignisgesteuerten Prozessketten angewendet.

Das somit entwickelte Referenzprozessmodell galt es im weiteren Verlauf zu validieren. Zu diesem Zweck wurden Modell und Organisationsstruktur sowie IT-Landschaft von DB Schenker Rail Romania einander gegenübergestellt. Dieser Abgleich führte letztlich zu einem Strategic-Fit mit welchem der Erfolg der Transformation und die Anwendbarkeit des Models bewiesen werden konnten.

Im Teil der kritischen Würdigung wurden das entwickelte Modell sowie die zugrundeliegende Transformation überwiegend positiv bewertet. Wenngleich der vorgegebene Untersuchungsrahmen limitiert war und eine Vielzahl von Annahmen und Vereinfachungen getroffen werden mussten, konnte das Ziel – ein anwendbares Referenzprozessmodell zu entwickeln – erreicht werden. Darüber hinaus konnte auch nachgewiesen werden, dass der klassischer Produktionssektor und die schienengebundene

Logistik eine stärkere Parallelität aufweisen als eventuell bisher angenommen. Nichtsdestotrotz wurde auch dargelegt, dass es sich dabei vielmehr um eine Grundlagenarbeit handelt die noch an vielen Stellen ausgebaut werden sollte. Weitere Untersuchungen könnten sich insbesondere auf eine umfangreichere und praxisorientierte Fallstudie konzentrieren sowie die horizontale Ausweitung des Modells anstreben. Vor diesem Hintergrund existiert mit der vorliegenden Arbeit eine wertvolle Basis für weitere Bestrebungen die mit der Auftragsabwicklung verbundenen Prozesse der Ressourceneinsatzplanung zu optimieren und die Übertragbarkeit produktionsbezogener Best-Practices voranzutreiben.

Acknowledgement

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Timm Schorsch, Bucharest, October 2011

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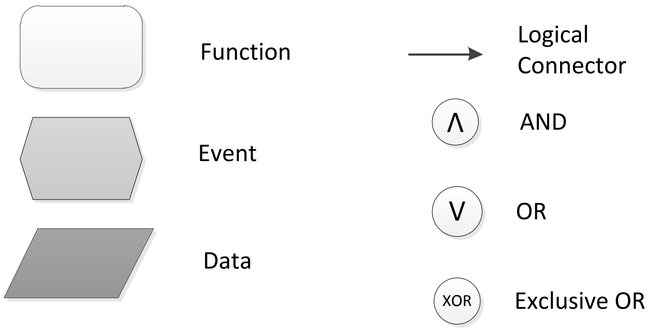
List of Abbreviations

APS	Advanced planning and scheduling
ATO	Assemble-to-order
ATP	Available-to-promise
CFR	Căile Ferate Române
CRM	Customer relationship management
CTP	Capable to Promise
CTV	Cargo Trans Vagon
DB	Deutsche Bahn
DBSR	DB Schenker Rail
DS	Detailed scheduling
EBIT	Earnings before interest and taxes
EPC	Event-driven process chain
EPG	Event-driven process graph
ERM	Entity-relationship model
ERP	Enterprise resource planning
ETCS	European Train Control System
GFR	Grup Feroviar Român
GPS	Global Positioning System
IT	Information Technology
LSD	Logistic Services Danubius
LSP	Lot-size planning
MPSP	Master production schedule panning
MRP	Material requirement planning
MTO	Make-to-order
MTS	Make-to-stock
NTKM	Net ton kilometer
PI	Production initiation
PM	Production monitoring
PTO	Purchase-to-order
RDP	Resource deployment planning
RPM	Reference process model
STI	Servtrans Invest
TFG	Transferoviar Grup
TRIP	Train Reporting in Production
UT	Unifertrans

Legend of Applied Event-Driven Process Chain Symbols



1 Introduction

1.1 Initial Position and Problem

Despite the increasing transport volumes in the road fright sector and the by the industry repeatedly demanded just-in-time transportation concepts, the rail freight sector has a high meaning throughout the whole European continent. For the future and especially with regard to cross-border transports, the rail-bound logistics will gain an even greater importance. With about 420 billion net ton kilometers (NTKM), about 16.5% of the overall transport volume is carried via railways. If the positive trend continues, the European national statistics offices predict a growth by 65% (compared to 2010) with an overall transport volume of more than 690 billion NKTMs in the year 2025.

A comparison between the different modes of transport reveals that the rail freight sector is still far behind when it comes to scientific approaches and optimal production concepts. For example, standardized process descriptions and supporting methods and tools for the operative order fulfillment process and this vein for the resource planning in the rail-bound logistics are practically nonexistent. Therefore, due to the fact that production capacities (in terms of infrastructure) cannot be extended infinitely and also because of the harsh competition with the road freight sector, a stronger involvement of science in the field of rail-bound logistics seems indispensable. In this context, the tremendous scientific interest and advancements in the classical (physical) production sector also have led to enormous efficiency improvements through various concepts in the field of advanced planning and scheduling (APS). Therefore, as concepts for planning and steering transportation processes in the road freight sector are not directly applicable to the rail freight sector due to different systematic constrains and restrictions, this raises the question whether it would be possible to apply methods, systems and tools from the production sector. Often these elements are combined in models that are designed from the process perspective and therefore referred to as *reference process models* (RPM). One practical example of an ambitious railway operator with strong potential for growth, but also potential for improvement with regard to the planning and steering of its order fulfillment processes, is DB Schenker Rail (DBSR) Romania.

To raise the question whether these reference process models are applicable to the rail freight sector breaks new ground. So far it was not proven whether classical production methods can be applied to the rail freight sector and, if so, to what extent. In any case, it has to be taken into account that despite various similarities, such as the resource allocation problem or the network character of both production systems, the rail freight sector is based on a completely different terminology and also comes along with many peculiarities and different constrains.

1.2 Goal and Approach

This work aims to overcome the above mentioned lack of scientific approaches for the order fulfillments process in rail-bound logistics. In particular, the overall goal is to develop a reference process model for order fulfillment in the rail-bound logistics based on methods, systems and tools from the classical production sector. However, as both sectors apply different terminologies and are partly driven by different constrains, first a transformation needs to be derived in order facilitate the direct application of production-related reference process models. Therefore, the goal is not to develop a completely new reference process from scratch, but to take elements from various existing models from specialist literature. In this context it can also be proven that, in general, such transformations are possible and, in particular, that the freight rail and the production sector are closer than initially thought.

The construction of reference process models can be supported by the application of development models. The approach of this work is based on a meta model, enhanced by further steps that also cover the transformation. Basis for the applied meta model is the work of Schütte[1] but also of other authors[2]. This model (Figure 1) can be understood as a road map for the following course of this work.

#	Step	Chapter
1	Definition of the Problem	1
2	Identify Sources of Information	2.3
3	Preparation of the Transformation	3
4	Description of the Problem Domain	4.1 – 4.3
5	Transformation	4.4 – 4.6
6	Development of the Model	5
7	Evaluation and Verification of the Model	6

Figure 1: Meta Development Model and Road Map

It is obvious that a precise description of the problem is the foundation for a high-quality and straight-forward modeling process. This step has already been taken within the introduction of this work. But before getting involved with the development, it is

[1] Cp. Schütte (1998), pp. 177-319 and especially 178-188

[2] For additional development models s. also Schwegmann (1999), pp. 165–184, Maicher, Scheruhn (1998), pp. 75–83 and Kallenberg (2002), pp. 46–51. Especially Kallenberg lists references to further literature on development models.

recommended to identify potential sources of information (existing models, blueprints of processes, etc.) that might be relevant to the actual modeling procedure (2.3). Additionally, even though it is not explicitly demanded by the meta model, the previous parts of chapter two provide insights into the field of reference process models in general in order to provide a proper basis, also, for uninitiated readers.

In a third step, the transformation needs to be prepared. This is achieved with two steps. First, the order acceptance process in the classical production is described with its characteristics and requirements (3.1). Second, standard patterns are introduced, based on which particular production systems can be characterized. These patterns will be the main tool for the transformation itself (3.2).

Also, previous to the transformation, the problem domain (i.e. the order fulfillment process in the rail-bound logistics) has to be defined in a detailed way (4.1 – 4.3). To ask what is relevant to the modeling process and where to draw the system boundary determines the guiding question of this phase. In a sixth step the transformation of the rail-bound logistics into a production related terminology takes place (4.4 – 4.6).

Finally, in the seventh phase, the actual modeling takes place by means of a consistent modeling technique (here: event-driven process chains) (chapter 5). At this point, existing models and processes will be aligned and combined based on the given requirements. Schütte recommends to conduct an evaluation at the end of this phase in order to verify the consistency of the constructed model.[3] For that purpose, chapter six contains a case study that applies the reference process model in the context of the above-mentioned railway operator DBSR Romania. Additionally, the critical acclaim (chapter 7) at the end of this work helps to conduct a comprehensive evaluation and, finally, an extensive summary (chapter 8) completes this work.

[3] Cp. Schütte (1998), p. 188

2 Theoretical Findings on Reference Process Models

Before elaborating on resource planning in rail bound logistics, a clear understanding of the tool that will be used to achieve the desired optimization of the planning processes is required. Hence, the initial position of this chapter is a literature-based definition of the term *reference process model*. Based on a top-down approach, a sharp definition will be derived from the broad term information model by narrowing it down to the domain of reference process models in particular. In this vein, the difference between reference models and reference *process* models also is pointed out (2.1). Then, a discussion of the benefits and risks of reference process models takes place (2.2). The last chapter (2.3) contains a summary of possibly relevant reference (process) models that could be used as blueprints for the following construction process.

2.1 Understanding the Term Reference Process Model

In the context of an etymological approach, *reference* may stand for suggestion[4] or recommendation[5]. On another level, reference also may be a link that points to another source (cross reference). Further, a *process* is defined as a sequence of single steps within a system[6] and, eventually, a *model* is a synonym for a pattern or plan that illustrates the reality on a superordinate level in a simplified and abstract way[7]. Thus, reference process models can be understood as a memory of knowledge from the process perspective, which can deliver a solution proposal for questions related to real issues.

This etymological understanding can now be substantiated by a specialist literature-based analysis of the term information model.[8] A top down-approach allows defining reference *process* models as a specific type of reference models, which, in turn, are a subclass of information models. Table 1 illustrates this differentiation by focusing on different attributes of information models. Shaded cells point out the specific characteristics of reference (process) models in general.

[4] Cp. Hadeler, Winter (2000), p. 2604
[5] Cp. Schütte (1998), p. 69
[6] Cp.Härbele (2008), p. 1055
[7] Cp. Stickler (1997), p. 595
[8] This appraoch can be found for example in Kallenberg (2002), Schwegmann (1999) and Schütte (1998).Other approaches and definitions based on single authors do mostly lead to more inconsistent definitions. Cp. Kallenberg (2002), p. 24

Table 1: Attributes of Reference Models and Reference Process Models[9]

Attribute	Characteristics		
View	Structure view		Behavior view
Claim to validity	Actual state model		Ideal model
Level of description	Functional concept	IT concept	Implementation
Range of applicability	Company model	Inner domain	Cross domain
Target group	Application model		Organization model
Degree of abstraction	Specific model		Type model
Level of the modeling language	Object model		Meta model

The **view** subsumes different perspectives that can be taken when setting up a model. A model that focuses on data or organizational units has a structure view. On the contrary, the behavior view subsumes the dynamic process and function perspective. This attribute (dark grey shaded) also clarifies the specific character of reference *process* model that has the main focus on the process view. All other criteria are still valid for both reference models and reference process models. Further, all reference models have in common that their **claim of validity** goes beyond the actual practice. They always strive to include the best (or ideal) practice. A simple summary of the current or actual practices without any improvements would contradict the reference character. The **level of description** refers to the question of how close the reference model is to the actual implementation and defines its relation to the IT.[10]. In contrast, the **range of applicability** refers to the scope of possible users. Reference models are different from company models as they apply to more than one user or company. They are either valid for a wide range of companies within different sectors and industries (cross domain), or are for a limited set of companies that belong to the same sector or industry. Similar to the attribute view, the attribute **target group** differs between models that can be applied for the purpose of process implementation and optimization (application models), on the one hand, and organizational design on the other hand. Since reference models are applicable to more than one company, their **degree of abstraction** is very high, which is why they are considered as type models. Specific models can be found only in exception cases, for example when embedding more concrete examples to facilitate future users in their understanding and application of the model. Eventually the **level of the modelling language** refers to the differentiation between object models, which are directly related to the reality, and meta models, which conduct the modelling by means of other models.

[9] Cp. Schwegmann (1999), pp. 53–55, Kallenberg (2002), pp. 25–28 and Schütte (1998), pp. 63–74.
[10] Cp. also Scheer (1997), p. 15

Based on additional references from literature, further main characteristics and requirements of reference (process) models can be summarized.[11] From an ideal point of view, these models have to:

- be reusable.
- be adaptable.
- have a modular structure that facilitates the reusability and adaptability.
- be universal, i.e. valid for wider range of applicants
- include the best practice.[12]
- facilitate user acceptance.[13]

2.2 Risks and Benefits

The following arguments represent a selection from literature, enhanced by arguments of the author, and are valid for both reference models and reference process models. Starting with advantages and benefits, one of the strongest arguments that can be found in various sources is that the application of reference process models leads to economy of time and cost saving effects in the construction and evaluation of (new) processes.[14] Moreover, Schwegmann lists improved communication due to a standardized terminology as one of the biggest advantages. He also points out that the process quality can be improved significantly by including best practices. Eventually, when applying reference process models for evaluation purposes, they can be considered as a neutral benchmark to overcome the user's subjective perspective.[15] Further benefits are obvious, such as risk minimization, as for most reference process models their practicability has already been approved beforehand in other use cases. Additionally the reduction of mistakes within the process development phase counts as an advantage.

Nevertheless, reference process models are not free from criticism. Their acquisition is time-consuming; not every reference process model is open to the public but they demand cost coverage; and the evaluation of company models by comparison is hindered by the variety of modeling languages[16] and different levels of detail. Therefore, the comparison might fail although the reference process model and the company model cover

[11] For a detailed introduction toward reference model requirement s. Schwegmann (1999), pp. 61–71.

[12] However, Scheer discusses the question if it is only the best practice that can be seen as a reference. Only aiming at the best practice leaves open how this knowledge could be made available. Usually companies are keen not to spread this knowledge. On the contrary to the best practice, the common practice is available to all market participants and hence in a wider sense the reference character has to be based on both, the best and the common practice. Cp. Scheer (1999), p. 7

[13] The usability and model quality are key factors.

[14] Cp. Thomas (2006), p. 485 and Schwegmann (1999), p. 58

[15] Cp. Schwegmann, Laske (2008), p. 144, Schwegmann (1999), pp. 57f. and additionally also Thomas (2006), p. 485

[16] Cp. Schwegmann, Laske (2008), p. 144

the same subject. This aspect also can be seen as the downside of standardization, which might lead an incompatibility between the model and actual business cases. In this vein, innovations also could be inhibited in case the reference process model does not offer any (or enough) possibilities for adaptation or extension (also known as customization) depending on certain situations.[17] The same effect also occurs if reference process model users develop a fixation on the model while neglecting individual aspects of their own field of application.

2.3 Suitable Reference Process Models and Sources

The acquisition of reference process models has been mentioned as a critical factor. Besides their limited public availability and high acquisition costs, a first market overview is also difficult. Fettke und Los strived to overcome this obstacle by creating an online catalogue for all kinds of reference models.[18] Based on a pre-selection by means of this online catalogue, the following six reference models have been identified as presumably relevant to the purpose of this work. Hence, models that do not include the process perspective in particular have been evaluated with regard to possible input for the reference process model of this work. In this chapter, their characteristics and content will be summarized to offer a basis of sources for the construction process in chapter 5. The models have been selected based on their stated possible domain of application, such as “Production Planning” and other domain descriptions that indicated a possible relevance to the subject of this work (i.e. production planning and order fulfillment). Models that have been labeled with “closed access” have been excluded from the beginning. As a special feature, the only existing reference model for vehicle based transportation (Kluger's Reference Model for Vehicle-based Transport Systems) will be examined to substantiate the assumption of missing standard planning approaches in the logistics sectors.

[17] Cp. Schwegmann (1999), p. 59

[18] Available under http://rmk.iwi.uni-sb.de (Fettke (2006). An abridgement of this catalogue is also available in Fettke et al. (2006), pp. 482f.

R/3 Reference Model	
Stated Domain	Enterprise Resource Planning
Creator	SAP AG
Modelling language	Event-driven Process Chain, Entity-relationship Model, Function Tree, Organizational Chart, Interaction Diagram
Availability	Limited
Relevant literature	Keller et al. (1999) Keller, Teufel (1999) Dickersbach et al. (2006) Teufel et al. (2000)
Content summary and usability	Driven by the wish to improve the process-oriented application of software, in the early 90s SAP AG started to introduce reference processes in parallel to their software products. These reference processes (esp. illustrated by EPCs) exemplify the application of the SAP R/3 respectively SAP ERP system based on various business cases. However, there are not many reference processes available to the public. But even so, only a detailed MTS planning process and a shortened MTO planning process could be identified in literature and this model seems very useful to the construction process – especially due to its direct relation to IT.

Y-CIM Model	
Stated Domain	Industrial Enterprise
Creator	Scheer, A.-W.
Modelling language	Event-driven Process Chain, Entity-relationship Model , Organizational Chart, Function Tree, Process Chain Diagram, Object Modelling and Design Technique
Availability	Open
Relevant Literature	Scheer (1997)
Content summary and usability	Based on a consistent architecture that describes different views (organization, data, steering and function) on business processes, an extensive reference process model exists for the following three main business processes: Production logistics, product development, and information and coordination.

Reference Model of Mertens and Griese	
Stated Domain	Industrial Enterprise
Creator	Mertens, P.; Griese, J.
Modelling language	Function Tree
Availability	Open
Relevant literature	Mertens (2009) Mertens, Meier (2009)
Content summary and usability	The reference model describes integrated information systems for different enterprise departments (e.g. production, controlling and product development) from both the operative and the holistic management perspective. Especially on the operative level, detailed function descriptions can be found for the production that makes the model highly relevant for the construction process.

Lang's Reference Process Building Block Library "Order Processing"	
Stated Domain	Order Processing
Creator	Lang, K.
Modelling language	Proprietary Reference Process Building Block-notation, RPB-specific Event-driven Process Chain
Availability	Open
Relevant literature	Lang (1997)
Content summary and usability	Lang addressed with his reference model the basic research of the field of reference process models. The subject was to identify to which extend standardized processes elements can facilitate the reusability of reference process models. Unfortunately, the included process building block library lacks the necessary comprehensiveness. However, the model contains useful findings on the subject of reference process model customization that are also relevant to the construction process.

Supply Chain Operations Reference Model (SCOR Model)	
Stated Domain	Supply Chain Management
Creator	Supply Chain Council
Modelling language	Wokflow Diagram, Graphical and Verbal Description
Availability	Limited
Relevant Literature	Holten, Melchert (2002) Sürie, Wagner (2008)
Content summary and usability	The SCOR-model represents a diagnostic tool for supply-chain activities across various domains. Its main purpose is to communicate and improve planning, making, sourcing, delivering and returning processes. However, it only contains process descriptions on an aggregated level with embedded best practice information for benchmarking. Hence, the application is only useful when there are already process descriptions available that can be measured against the best practice processes.

IOOP Reference Model	
Stated Domain	Production Planning and Control Systems
Creator	Kees, A.
Modelling language	UML Class Diagram
Availability	Open
Relevant literature	Kees (1998)
Content summary and usability	The IOOP Reference Model is not based on an object model but on a meta model approach. It contains a guideline for how to transform conventional production related reference (process) models into object-oriented modelling language. As this work does not require a meta model, the IOOP Reference Model will not be used here.

Kluger's Reference Model for Vehicle-based Transport Systems	
Stated Domain	Vehicle bases transport
Creator	Kluger, M.A.
Modelling language	Proprietary Process Model
Availability	Limited
Relevant literature	Kluger (1999)
Content summary and usability	The purpose of the model is to facilitate the development of in-plant transportation systems (such as automated guided vehicles). The scope of the model does not include the actual operation of the system and also excludes the operations (program) planning itself. The purpose of the reference process model of this work is the operations planning and not the planning of the entire transportation systems. Therefore, Kluger’s Reference Model – as the only existing model for the domain of transportation – does not suit the requirements of the construction process.

Based on the content summaries above, the **R/3 Reference Model**, the **Y-CIM model** and the **Reference Model of Mertens and Griese** will be selected as sources for the construction process in chapter 5. Additionally **Lang's Reference Process Building Block Library "Order Processing"** could be helpful for the topic of customizing. All other models will not be considered in the further course.

3 Order Fulfillment

This chapter provides an introduction to the order fulfillment process in the context of the production sector in the narrower sense (3.1). In order to set up a basis for the development of the reference process model, the main focus will be on the connected resource planning and controlling tasks from a process perspective. The illustration of the order fulfillment process also helps to define the scope of this work and the reference model application area. In a second step, this chapter summarizes different criteria that exist to classify different order fulfilment processes (3.2). The resulting patterns are the foundation for the transformation of the rail-bound logistics system into a production system.

3.1 The Order Fulfillment Process

In the context of the order fulfillment process, a differentiation between the technical and the commercial order fulfillment processes is useful.[19] The technical part is initiated by order forecasts or concrete customer orders and incorporates all decision and execution activities necessary to process and accomplish the customer order. It ends with the completion of the product.[20] Taking into account that the planning activities play an important role in the technical order fulfillment process, in some cases the term *production planning and control* is used as a synonym for the technical perspective.[21] In comparison, the commercial perspective refers to all activities that have a direct interface with the customer or market. Elements that can be subsumed under this perspective are, for example, the shipment of goods, the sales activities, the billing, the order acceptance and all customer service activities.[22] Figure 2 marks the difference between the technical and commercial order fulfillment processes and also illustrates the scope of this work. Because the optimal usage of resources depends especially on the decision activities that are carried out within the order acceptance process and the technical order fulfillment process, the following elaborations are clearly circumscribed by the incoming order request, on the one hand, and the completion of the product on the other hand. Elements relevant to this work

[19] Cp. Joachim Käselau (2002), p. 8
[20] Cp. Hellmich (2003), p. 7
[21] Cp. Joachim Käselau (2002), p. 9 and Pfohl (2004), p. 80
[22] Cp. Joachim Käselau (2002), p. 9 and Hadeler, Winter (2000), p. 232

are imbedded in the grey box in Figure 2: Order acceptance, production planning, and the production process itself, including all necessary controlling activities.[23]

In the following figure, this differentiation will be used to illustrate the order fulfillment process in a detailed way. This work applies event-driven process chains (EPC) as a consistent illustration technique. If there is no high detailed level required, and if simplifications do not affect the understanding, processes also will be modeled with simplified event-driven process graphs.[24]

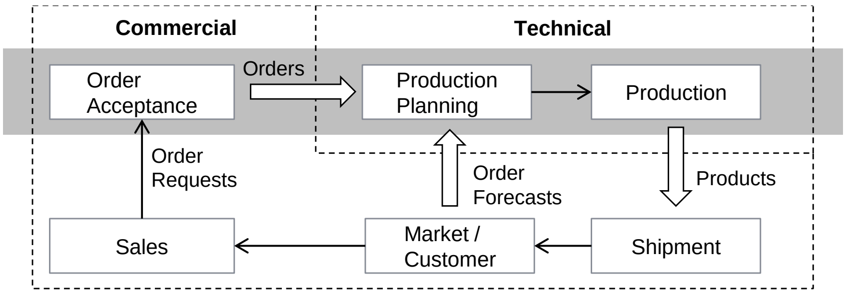


Figure 2: Comparison of the Technical and Commercial Order Fulfillment Process[25]

Before elaborating on the three different core processes, it has to be taken into account that their characteristics and interactions depend highly on the peculiarities of each concrete order fulfillment process. Consequently, the following explanations represent a compromise between specificity, on the one hand, and universality on the other. The location of the order penetration point, especially, has an important influence on the characteristics of the order fulfillment process[26], as it marks the transition from forecast-driven processes to customer-order-driven processes in the production.[27] The customer-order-driven processes also are referred to as pull processes, whereas the forecast-driven-processes are referred to as push processes.[28] Figure 3 shows the four different options for the order penetration point that are usually discussed in literature.

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[23] Cp. Joachim Käselau (2002), pp. 9f. and especially for the order acceptance process Spengler et al. (2008) and Spengler et al. (2010)
[24] Although the EPC (respectively EPG) technique is widely used and discussed in literature there are some minor differences in the illustration with regard to different authors. The consistent illustration used in this entire work bases mainly on Rosenkranz (2006), pp. 20–31. Some enhancements have also been taken from Becker (2008), pp. 61–68 as well as from Fischer et al. (2006), pp. 69f.. A detailed legend can be found at the beginning of this work.
[25] Based on Joachim Käselau (2002), p. 9
[26] Cp. Hellmich (2003), p. 12
[27] Cp. Rehkopf (2006), p. 9
[28] Cp. Hellmich (2003), p. 13

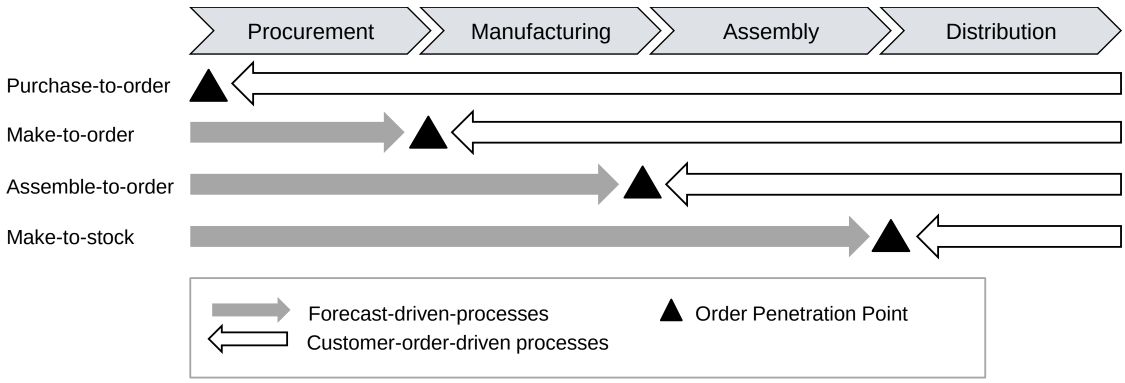

Figure 3: Different Locations of the Order Penetration Point[29]

In case of **purchase-to-order** (PTO), the production is carried out in a customized and, most likely, non-repetitive way. Usually, the products show a very complex structure and the customer influence affects even the long-term main production schedule and the entire procurement process. A common example is the production of a ship[30].

A production that is subsumed under the term **make-to-order** (MTO) still compromises a high degree of customer influence, although the procurement planning is already organized stochastically. The production complexity is also high but, in most cases, already pre-defined materials, machines and tools are used.

Assemble-to-order (ATO) refers to cases with non-customized manufacturing but with an assembly based on concrete orders and customer preferences. The product complexity is reduced due to the usage of standardized components or assembly groups.

Make-to-stock (MTS) production has standardized products that are only manufactured and assembled based on disposal forecasts. The interface with the customer is represented by the warehouse and the customer has no opportunity to execute influence on the pre-located processes or, respectively, on the product design.

3.1.1 The Order Acceptance Process

Within the order acceptance process, the company decides whether to accept or reject a customer order. Figure 4 illustrates this process, pointing out the four main assessment criteria. At the beginning of each acceptance process, the company has to assess the creditworthiness of the customer and whether the order is feasible from the technical point of view, which means to check if the ordered product is part of the feasible product portfolio.[31] If one of these two criteria cannot be fulfilled, the order can be rejected. After

[29] Based on Rehkopf (2006), p. 9. For further information on the order penetration point s. also Hellmich (2003), pp. 12–15

[30] Cp. Rehkopf (2006), p. 10

[31] Cp. Kiener et al. (2009), p. 55

these two first steps,the ATP and CTP checks are carried out. The available to promise (ATP) check identifies whether there is already-existing inventory to fulfill the customer order. If there is enough inventory to fulfill the customer order, the order can be confirmed immediately (not shown in Figure 4). Or, if the inventory is insufficient to fulfill the order, the capable to promise (CTP) check evaluates if the available production capacity covers the capacity that is required to fulfill the order. The CTP check is carried out on an aggregated level and differs from the final scheduling and capacity planning within the production planning process (s. 3.1.2).

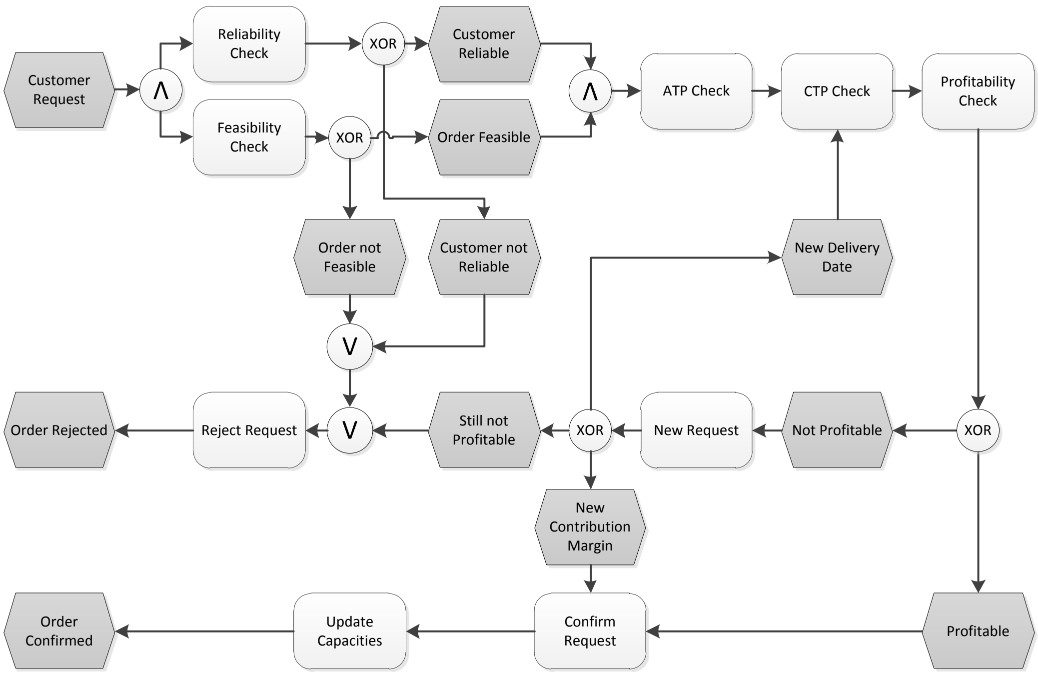

Figure 4: The Order Acceptance Process[32]

Subsequent to the CTP check, the profitability check compares the estimated production costs and the customer's willingness to pay. If the willingness to pay exceeds the production costs, the order is classified as profitable. Otherwise, the company enters an additional negotiation procedure with the customer that can result either in a modified order in terms of the delivery date followed again by a CTP check, in a customer's greater willingness to pay, or in the rejection of the request. In comparison, a profitable request leads to an order confirmation and capacity update.[33]

The importance of this process depends greatly on the order fulfillment characteristics. For example, a make-to-stock order fulfillment will not require an (extensive) order acceptance process, as all production processes are triggered and run independently from the

[32] Based on Spengler et al. (2010) and enhanced by Kiener et al. (2009), p. 55

[33] Cp. Spengler et al. (2008) and Kiener et al. (2009), p. 55

customer. Only on the warehouse side a decision process, assessing whether to sell the product to the customer, would be conceivable. On the contrary, the acceptance process gains more importance if the products are customized and the required production capacity exceeds the available capacity.[34]

3.1.2 Production Planning

In general, the term *production plann*ing refers to three different hierarchically organized levels.[35] The top level is referred to as the strategic planning, with a planning horizon of about five years. The planning that is carried out there is more general and does not directly deal with the realization itself. For example, strategic decisions might refer to the choice of a location for a new production site or the content of the production program (product development). Subsequently, the tactical planning concretizes the strategic input within a time horizon of about one to five years. Planning tasks refer, for example, to the midterm production program or the optimal vertical range of manufacture. Eventually the operative planning, with a planning horizon up to one year, transforms the tactical input into concrete directives for the production system and, hence, represents the interface to the production control and the actual value-added process. As the strategic and tactical planning are independent from the order penetration point and not directly connected to the accomplishment order fulfillment process[36], in the following the focus will fall heavily on the operative planning tasks.[37]

Also here, the characteristics of the planning process depend greatly on the concrete order fulfillment. However, when reducing the different findings and studies to a common denominator, five distinct main planning modules can be identified: master production schedule planning (MPSP); material requirement planning (MRP); lot-size planning (LSP); resource deployment planning (RDP); and detailed planning (DP). These elements are exemplified by Figure 5 (Production Planning).

[34] Cp. Spengler et al. (2010)
[35] Cp. Corsten (2004), pp. 233ff.
[36] Cp. Rehkopf (2006), p. 12
[37] Also in literature, all other elaborations on the order fulfillment process have their starting point on the operational level. Cp. for example Westkämper (2006) and Joachim Käselau (2002).

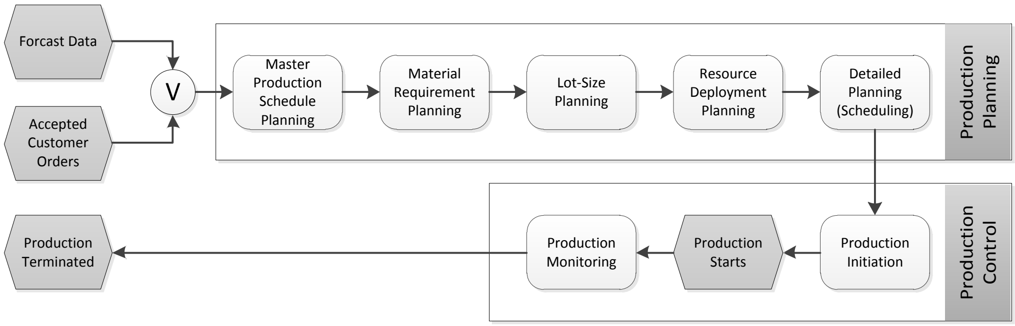

Figure 5: Operative Production Planning and Production Control[38]

The **master production schedule planning** specifies which quantities of which products have to be produced for which due dates. Consequently, this step defines the primary demand based on an aggregated resource planning for distinct periods. The master production schedule planning can be based on both customer order forecasts and already accepted customer orders. This planning phase is also the one with the most variable time horizon. There are order fulfillment processes that require extensive planning in advance and, hence, the time frame may comprise up to 24 months and overlap with the tactical planning.[39] In other cases, with less complex products but a high degree of flexibility, the considered time frame may be only about a few weeks or even less. In any case, this phase is crucial, because incorrect decisions can lead to a capacity overload or lacking usage of capacity in the actual production process.

The **material requirement planning** determines the required material in terms of raw materials, prefabricated parts and also operating supply items and additives. Therefore, the purpose of this phase is to ensure that all necessary materials are provided at the right quality, in the right amount, at the right place in the right time. In this way the secondary and tertiary[40] demands are derived from the pre-defined primary demand.

The **lot-size planning** determines how many items of a distinct product will be produced in succession. Eventually, the results of this phase are roughly time-phased internal and external orders that undergo a more detailed planning within the subsequent resource deployment planning. In some literature, the material requirement planning is introduced as an integrated part of the lot-size planning, as the amount of required material per period depends on how many main products will be produced in which time frame.

Within the **resource deployment planning** a concrete allocation of the production capacity takes place, for example the assignment of orders (products) to distinct resources (machines

[38] To identify this universal model, especially the following sources have been taken into account: Günther, Tempelmeier (2007), Westkämper (2006), Joachim Käselau (2002) and Kurbel (2005).
[39] Cp. Westkämper (2006), p. 182
[40] Secondary demand subsumes all raw materials and prefabricated parts. On the contrary tertiary demand refers to all operating supply items and additives.

and personnel). This planning task is based on the milestones set by the lot-size planning, whereas now the orders are transferred from a roughly time-phased schedule into a detailed production schedule. Therefore, the interface between lot-size planning and resource deployment planning marks the transition from period-based planning to continuous planning. Assuming unlimited capacity, the start and the end dates of the regarded production process are determined. But as this lead-time scheduling most certainly causes unbalanced usage of resources, the capacity adjustment is required as a second step. The ideal case are fully utilized resources every time, which means that it is best to schedule an order for exactly the same time when the previous order is fulfilled and the resources become available again. To come closer to this goal, there are different measures for capacity adjustment, such as outsourcing, additional working hours or additional rented resources.

The **detailed planning** prepares the scheduled orders for the production initiation (s. 3.1.3). In some cases, all orders requiring a rescheduling have already been identified within the capacity adjustment. Otherwise, the detailed planning eliminates the last the remaining capacity conflicts by applying a very detailed time pattern in terms of hours or minutes. At the latest, at this point the necessary transport times between the different resources have to be taken into account also. Additionally, this phase conducts an available check to ensure that the required secondary and tertiary demand is covered. The detailed planning directly merges into the production control and can be carried out by means of a control center.

Table 2 contains a brief summary of the planning tasks in each phase mentioned above. Additionally, the headline contains information about possible planning horizons within the different stages. However, due to different requirements of each distinct order fulfillment process, the horizons have to be defined relatively roughly to cover all possible cases.

Table 2: Production Planning Tasks

Master Production Schedule Planning	Material Requirement Planning	Lot-Size Planning	Resource Deployment Planning	Detailed Planning
Months / Weeks	→	→	→	→ Hours / Minutes
• Planning of primary demand • Determine delivery dates ⇨ Gross planning	• Inventory determination • Inventory management • requirements explosion • Procurement planning ⇨ Secondary and tertiary demand	• Determine lot-sizes • Rough allocation of orders to resources ⇨ Lot-size plan	• Determine capacity demand • Lead-time scheduling • Allocate orders to resources • Adjust resource usage ⇨ Production schedule	• Preparation for production initiation • Eliminate capacity conflicts • Availability check of secondary and tertiary demand ⇨ Detailed schedule

3.1.3 Production Control

Within the production control, another two functions can be identified: the production initiation (PI) and the production monitoring (PM) or real time control activities, which take place in parallel to the value-added process (Figure 5, Production Control). The **production initiation** can be regarded as a trigger that starts the value-added process and ensures that that the previously set-up plan is put into practice. The main task in this context is the provision of information. Various paper forms like material requisition cards, batch cards or work orders facilitate the information supply. Nowadays, paperless systems (e.g. graphic displays at the workplace) also gain an increasing relevance in this field.

Once the production process is initiated, the **production monitoring** takes over. It constantly compares the target specification of the previous plans to the actual status of the production process. However, there is still a certain degree of freedom that allows deviation from the schedule and capacity plan in order to constantly ensure a continuous material flow and usage of resources.[41] In this vein, the troubleshooting represents an important task in this phase. Production breakdowns, due to short-term sick leave or machine breakdown, for example, have to be compensated by immediate operational measures. Table 3 briefly summarizes the tasks of production initiation and production monitoring.

[41] Cp. Westkämper (2006), p. 194

Table 3: Production Control Tasks

Production Initiation	Production Monitoring
• Bundle information from the production planning • Create forms (paper and paperless) • Allocate information and initiate production ⇨ Production starts	• Comparison of target planning and actual status • Ensure continuous material flow and usage of resources • Troubleshooting ⇨ Production and production completion

3.1.4 Practical Implementation

Planning Models and Planning Approaches

The introduction of the planning modules above might suggest that there are no, or only a few, interconnections and that all planning and controlling tasks can be carried out independently of each other. However, a closer investigation reveals a variety of interdependences between these modules and, thus, an optimal approach demands an extended linkage between them.[42] For example, the determination of lot-sizes within the quantity planning effects the concrete scheduling in the next phase. The lot-sizes cannot be considered as optimal if they are neglected, whether there are suitable time slots in the production schedule, and, in turn, the production schedule might suffer from pre-defined lot-sizes that inhibit an optimal scheduling of multiple orders.

A solution to the above planning tasks can be achieved with operations research planning models. In light of the highly interdependent planning tasks, these models can be allocated to two different planning approaches, which eventually also can merge into a third. On the one hand, partial models are part of the classical successive planning in which each planning problem is solved mostly independently from all other planning problems[43]. Especially subsequent problems, especially, are not taken into account, which eventually leads to optimal single solutions, constituting a non-optimal package solution.[44]

On the other hand, integrated models strive to overcome isolated single solutions by integrating a variety of different problems within one model. In most cases, the solution is no longer achieved by pure mathematical functions that have to be optimized, but by computer-based simulation models. Due to their high demand of computing power, in the past decade these models have been very difficult to handle. But with the tremendous

[42] Cp. Fandel et al. (2011), pp. 96–98
[43] An example for a mostly isolated optimization model is the HHPLAN model by Gunther et al. which aims to identify the optimal primary demand under the restriction of minimized inventory costs and additionally required capacity. Cp. Günther, Tempelmeier (2007), pp. 168–172
[44] Cp. Kurbel (2005), pp. 34–37

advancements in the computer industry in recent years, it has become possible to solve more complex integrated models.[45] Nevertheless, until today there has been no model that was able to solve all production problems within one single holistic approach. Literature remains skeptical that this ever will be achieved.[46]

Additionally, there exists a third approach that can be understood as a combination of partial and integrated models. These so called hierarchical models are based on four main mechanisms in order to overcome isolated solutions, on the one hand, but also to reduce complexity on the other:[47]

- Hierarchical planning levels: Results from the superior levels are input for the lower levels.
- Decomposition: Simulation models are divided into partial models that are linked via defined interfaces.
- Aggregation: Data and decision variables are combined in order to reduce complexity (e.g. product groups or extended planning periods).
- Continuous Planning: Overlapping planning periods allow the integration of feedback cycles.

Main Drivers

Because the order fulfillment process, as such, is not straight-forward but is in need of drivers that provide directions and facilitate decisions, there are different approaches towards targets that can to be taken into account when running through the process. According to Fandel, the classical method to derive the right decisions within the order fulfillment process is the calculation of the contribution margin.[48] Kurbel generalizes this statement even further as he suggests to maximize the economic efficiency described by the quotient output against costs, whereas the main focus is on the cost side, since in many cases the achievable output (in terms of quantities and revenues) is determined by the market.[49] On the contrary, with the help of the Revenue Management an approach that aims to maximize the output side also exists.[50]

If the Revenue Management methods are not applicable, and if it is not trivial to determine the actual costs, alternative targets can be taken into account. These alternative targets resemble the connected costs in an approximated way, for example minimizing machine downtime (downtime costs), reducing quantities on stock (storage costs) or

[45] Cp. Kurbel (2005), pp. 37–40
[46] Cp. Kurbel (2005), p. 37
[47] Cp. Kurbel (2005), pp. 41–44
[48] Cp. Fandel et al. (2011), p. 6
[49] Cp. Kurbel (2005), pp. 8f..
[50] E.g. Rehkopf (2006)

avoidance of delivery delays (contractual penalty, loss of goodwill).[51] However, the application of alternative targets can lead to target conflicts, which eventually require the definition of target priorities.[52] One of the prevailing conflicts arises between the technical and commercial order fulfillment, between production and sales. While the production wishes an extensive forward planning to maximize its resource utilization, the sales department aims to deliver a variable product portfolio to satisfy individual customer needs.[53]

Application Software

Today, there are various software solutions available to support the introduced planning tasks within the order fulfillment process. Previously, there was distinct software specifically designed for the production planning and control tasks (PPC-System[54]). But in order to handle increasing complexity and the interdependencies between different departments and fields, current Enterprise Resource Planning (ERP)-Systems follow a holistic approach. Usually these extensive systems include different modules, such as production planning modules (i.e. the former PPC Systems), sales modules, accounting and controlling modules and many more. Consequently, there are no longer alone standing PPC-Systems but integrated production planning and control modules. In the end, which modules are implemented depends on the customer. From the point of view of the order fulfillment process, the benefit can be seen in the possibility to link and integrate the above-mentioned planning to other enterprise functions. A market leader in terms of ERP-Systems is the SAP AG, which offers their ERP-System SAP ERP with a huge variety of modules.[55]

[51] Cp. Kurbel (2005), pp. 9f.
[52] Cp. Kurbel (2005), pp. 10ff.
[53] Cp. Fandel et al. (2011), p. 7. For further information on target conflicts s. also Kurbel (2005), pp. 10ff. and Westkämper (2006), p. 181
[54] In German also known as “Produktionsplanung- und Steuerungssystem”
[55] Cp. Kurbel (2005), pp. 27–33 and Kiener et al. (2009), p. 33

3.2 Patterns of the Order Fulfillment Process

The explanations above have shown that a variety of different order fulfillment processes exists. As the order fulfillment production systems can differ in several diverse criteria, it requires clearly structured patterns to enable an objective classification. According to Günther et al., some criteria are already directly related to well-known planning problems. Hence, the classification of an order fulfillment process provides the basis for the construction of decision models and the identification of solutions regarding specific production problems. Besides, these patterns facilitate the selection of suitable standard software.[56] By summarizing them, this part provides a framework to support the subsequent transformation of the rail-bound logistics systems and its orders into a production-related terminology and, hence, the development of the reference process model.

Several authors already have elaborated on the classification of order fulfillment processes. The extensive research in this field has led to numerous different criteria, which become easier to handle by embedding them into a meta structure. Dyckhoff and Spengler and also Günther and Templemeyer suggest following the input-transformation-output concept and, hence, to distinguish between three classes of criteria: input-related criteria, process-related criteria and output-related criteria.[57] A reader-friendly illustration is achieved by using a morphological box. The following criteria represent a selection from literature and various sources[58], while those that are not directly relevant to the transformation have been excluded.

3.2.1 Output Related Criteria

On the output side, there are six different criteria to classify an order fulfillment process (Table 4). These criteria also are referred to as program-related criteria.[59] A first differentiation should be made between a **real assets production** (production of physical goods) and a **service production**. However, in the context of a service production, the application of some other criteria mentioned below might be ambiguous and not always consistent across literature.[60]

[56] Cp. Günther, Tempelmeier (2007), pp. 10ff.
[57] Cp. Günther, Tempelmeier (2007), p. 10 and Spengler, Dyckhoff (2010), p. 13. When addressing output-related criteria, Gunther uses the term “program-related”.
[58] Cp. Spengler, Dyckhoff (2010), pp. 13–27, Hellmich (2003), pp. 15f., Kurbel (2005), pp. 23–26 and Günther, Tempelmeier (2007), pp. 10–22
[59] Günther, Tempelmeier (2007), p. 10
[60] Cp. Spengler, Dyckhoff (2010), p. 16

The purpose of each production system is to produce the desired **main products** that have been defined in the production program. Output objects that do not reflect the main purpose of the system but are produced in connection with the main product are referred to as **side products**. With regard to the main products, there are systems that do not only produce one distinct product (**single product production**) but several different products (**multiple products production**).

The criterion *relation to market* resembles the order penetration point (**PTO**, **MTO**, **ATO**, **MTS**) discussed above (Figure 3). In this regard, the question of how the order is initiated arises. The **master agreement** is a long-term contract that contains an agreement about a certain order fulfillment over a longer period of time, and the production of a bigger quantity of products. In contrast, a **single order** refers to only one distinct item or a bundle of items, where the quantity is lower and the time frame shorter. In case of **MTS** order initiation, the order is not initiated by a contract itself but by the absorption of a finished product from stock.

Eventually, the product complexity reaches from **single part products,** which consist of only one part (e.g. brass candleholders, steel slaps), up to very **complex products,** which consist of multiple parts (e.g. automobiles, construction machines). Within this continuum, **products with multiple parts but a comparable simple structure** (e.g. kitchen machines, furniture) also can occur.

Table 4: Output Related Criteria

Criteria	Characteristics				
Character of main products	Real assets production			Service production	
Output type	(main) products			side products	
Number of main products	Single product production			Multiple products production	
Relation to market	PTO	MTO		ATO	MTS
Order initiation	Master agreement		Single order		MTS
Product composition	Multiple parts with complex structure		Multiple parts with simple structure		Single part

3.2.2 Process Related Criteria

Table 5 shows five different process related criteria. Within the production process, a differentiation can be achieved by the number of production units. **Single-stage** processes consist of only one production unit. In contrast, a **multi-stage** processes consist of multiple production units where the output of a preceding stage represents the input of a subsequent stage. Both, single- and multiple-stage production processes are classified as **circular** if the output of one production unit makes up the input of the same or preceding production unit. Moreover, a further investigation of the production network reveals the structure of the material flow. Four elementary shapes can be identified here: an **even** material flow (without branching); a **convergent** material flow (synthetical or composing); a **divergent** material flow (analytical or disassembling); and a **regrouping** material flow (interchanging). In case the sequence of production units is not predefined, a production system with a **flexible** sequence exists. Or, the production system has a **fixed** sequence. If the products leave the production process in regular intervals (or if there is a production of constantly produced flow goods) the material flow is considered **continuous**. On the contrary, if items (or flow goods) are produced in irregular intervals the material flow is **discontinuous**.

Although the lot-sizes are characterized by a continuum (from one to indefinite), there are three qualitative terms to describe how many items are produced in succession. If there is only one distinct product that is followed by a different product, a **single**-lot-size production exists. On the contrary, an indefinite number of products that are produced over a long period of time are referred to as **mass production**. If there is a defined number of products that are produced in succession on the same production line (or unit) before a different lot is initiated and produced, a **batch production** exists.

Table 5: Process Related Criteria

<table>
<tr><th>Criteria</th><th colspan="12">Characteristics</th></tr>
<tr><td>Number of connected production units</td><td colspan="4">Single-stage</td><td colspan="4">Multiple-stage</td><td colspan="4">Circular</td></tr>
<tr><td>Structure of material flow</td><td colspan="3">Even</td><td colspan="3">Convergent</td><td colspan="3">Divergent</td><td colspan="3">Regrouping</td></tr>
<tr><td>Sequence flexibility</td><td colspan="6">Flexible</td><td colspan="6">Fixed</td></tr>
<tr><td>Continuity of material flow</td><td colspan="6">Continuously</td><td colspan="6">Discontinuous</td></tr>
<tr><td>Lot sizes</td><td colspan="4">Single production</td><td colspan="4">Batch production</td><td colspan="4">Mass production</td></tr>
</table>

3.2.3 Input Related Criteria

Eventually, criteria to classify the input side of a production system also exist (Table 6). A basic classification on the input side is the assessment of the market desirability of the input factors. The question is whether, in general, the regarded factors are desired by the market (**production factors** with a positive market value), whether they are undesired and rejected by the market (**undesired factors** with a negative market value, e.g. scrap tires or toxic substances), or if the market is neutral towards them (**by-factors** or freely available factors, e.g. fresh air or rain water). However, there are also production systems with the purpose to transform (by the market) undesired input factors into neutral or even desirable ones. Hence, their attitude towards undesired input factors is contrary to the market perception.[61] Moreover, input factors can be classified according to their quality of transformation within the production process. **Unchanged factors** leave the production process unaltered. They could be both input and output factors (e.g. labor services or machines). On the contrary, **converted factors** alter their quality as they directly become part of the end-product (**directly** converted factors) or are irretrievably consumed in the production process (**indirectly** converted factors, e.g. additives). Also, unchanged factors can be sub-classified again into **active** unchanged factors (e.g. machines, tools or manpower) and **passive** unchanged factors (e.g. buildings or knowledge).

Furthermore, a differentiation between **external input factors** and **internal input factors** is possible. External input factors are not directly at the company's disposal. Examples are objects that are made available by the customer or the services of alien providers. On the contrary, internal input factors are objects that emanate from the company's sphere of influence. They might be, for example, self-produced, prefabricated parts or purchased factors from reliable markets. Eventually a production also can be classified according to the share of its input factors. There are **material** input factors (e.g. raw materials), **equipment** input factors (e.g. machines), **labor** input factors and **information** factors.

Table 6: Input Related Criteria

Criteria	Characteristics			
Market desirability of input factors	Production factors	Undesired factors	By-factors	
Quality transformation during the process	Unchanged factors		Converted factors	
Performance of unchanged factors	Active		Passive	
Relation of converted factors to main products	Direct		Indirect	
Availability of input factors	External factors		Internal factors	
Split of input factors	Material intensive	Equipment intensive	Labor intensive	Information intensive

[61] E.g. the deployment of scrap tires in a waste-fuelled power plant. Cp.

4 Analysis and Transformation of the Rail-Bound Logistics

This chapter deals with the analysis and description of rail-bound logistics and aims to transform the logistics system and its connected transport orders into production-related terminology. First, a brief introduction to the railway sector will be given (4.1). In this context, a market overview based on key figures will be illustrated from the historical, current and forecast perspectives. A discussion of the meaning of rail freight transportation and its challenges completes this picture. Then, the rail-bound logistics is discussed in-depth by differentiating between the logistics system from a technical point of view (4.2) and the different orders that can occur within this system (4.3). This discussion also represents the basis to derive an order fulfillment process from the production perspective. Based on the patterns (of different order fulfillment processes) introduced above, the logistics system and the transport orders will be transformed into an equivalent production system (4.4) and equivalent product orders (4.5). The transformation logic is illustrated in Figure 6. The final sub-chapter (4.6) summarizes the requirements of the specific order fulfillment process that have been identified by means of the transformation.

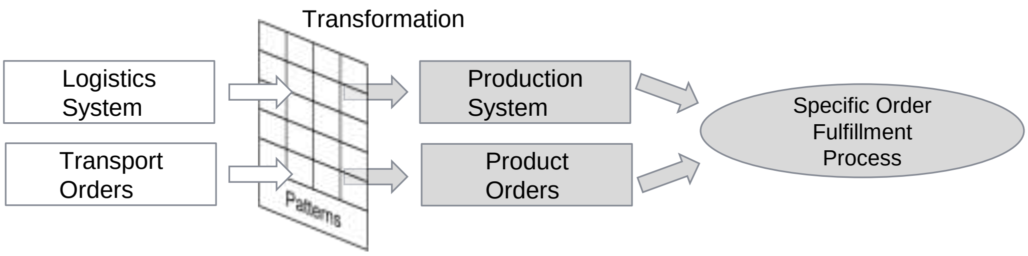

Figure 6: Transformation Logic

4.1 The Rail Freight Sector

The rail freight sector comprises all transports of goods that are carried on railways by means of freight railway vehicles. It can be clearly distinguished from the transportation of passengers (rail passenger sector).[62]

Across Europe, the development of the rail freight sector in the last 30 years has hardly been a success story. In a market characterized by a vigorous growth, in contrast to the road freight sector, the rail freight sector could not benefit from the upturning economy. Since the 1970s, it has consistently been losing its modal split. But since 2002, the

[62] Cp. Kummer (2006), p. 71

transport performance, in terms of transported net tons, shows a positive trend.[63] Hence, when judging about the development and the current and future meaning of the freight railway sector, a differentiation between an inter- and intra-sector perspective is necessary. With regard to the modal split (inter-sector perspective), the figures still show a poor development although the downside trend is becoming more moderate (Figure 7). Coming from over 50% modal split in the 1950s[64], it decreased over time to 16.7% in 2010 and it is expected to decrease further to 16.5% in 2015. The graph also shows that the road freight sector can be considered the strongest competitor to the rail freight sector. The lost modal split can be found on the road freight sector side.[65]

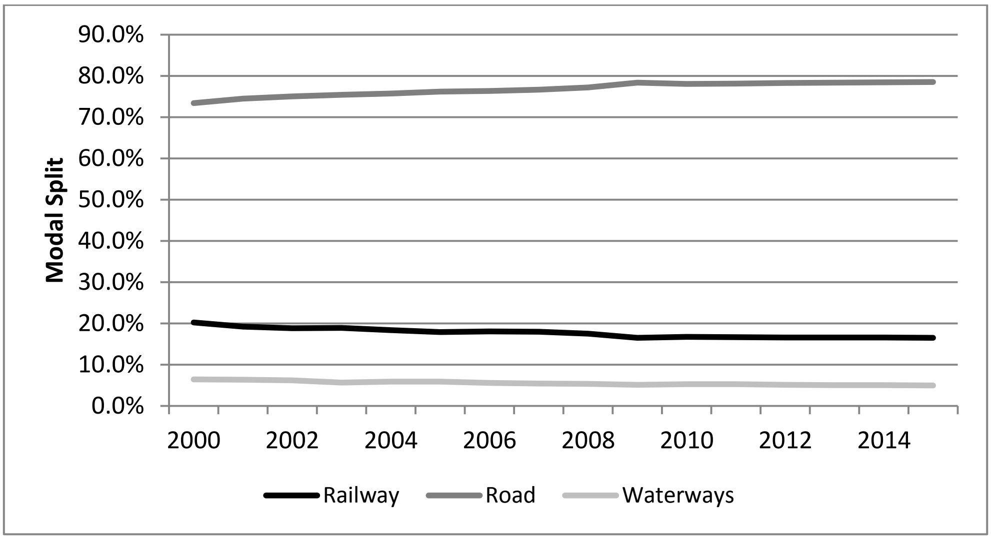

Figure 7: Development of the Modal Split[66]

Poor development and forecasts of the modal split have their cause in both structural characteristics, which are immanent to the railway system, and changing market requirements, on the one hand, as well as in the diverse historical developments across the European countries on the other. Regarding the immanent characteristics, Kummer names the high share of fix costs and the lack of flexibility (due to the relatively inflexible railway network) as the main downsides of the system.[67]In addition, changing market needs came along over recent decades: a decreasing demand in bulk goods transport, a spatial diversification of the production and ,hence, the need for highly flexible logistics solutions

[63] Cp. Rothengatter (2002), pp. 28f. and Hilbrecht, Brüssel (2002), pp. 46f.. This conclusion can also be found in other sources (e.g. cp. also Arnold (2008), pp. 727ff.. However, this work desists from expressing this conclusion in quantitative terms due to multiple inconsistent sources of statistics before 2000. Partly the sources of the provided data cannot be verified anymore and also different reference frameworks have been used (e.g. EU 15, EU 27, including or excluding non-EU member states).
[64] 2010), p. 60
[65] Cp. Rothengatter (2002), p. 29 and Kummer (2006), p. 72
[66] Supplied by DB Mobility and Logistics AG and based on data from Federal Statistical Offices.
[67] Cp. Kummer (2006), p. 72

that directly serve remote regions, and an increasing demand in transport quality and permanent goods supervision.[68]

On another level, the diverse historical development in different countries across Europe has led to a railway system that is incapable of fulfilling the increasing demand in international, nonstop border crossing transport connections. National protectionism, which has its roots in the wartime of the early the 20th century, has caused both a lack of technical network interoperability[69] and a non-liberalized market due to national regulations and high entry barriers for outside railway providers. These Europe-wide differences have added to the immanent downsides of the railway system and, consequently, led to the loss of modal split. A far more liberalized road freight sector creates a distortion of competition and amplifies the modal split development even further.[70]

Despite the disadvantages and obstacles listed above, since 2002 the intra-sector perspective reveals a positive development for the rail freight sector (except for the years of crises 2007 and 2008). The last two years the transport volumes have increased again and the forecast predicts a positive trend that will reach the hitherto peak with about 460 billion NTKMs (2007) in 2015 again (Figure 8). Also, there are several advantages of the rail freight sector that are becoming more and more relevant to the market, including the fact that rail is a particularly safe and environmentally friendly mode of freight transport.[71] Related to one ton of transported goods, the freight rail sector emits about three times less CO_2 compared to the road freight sector.[72] Moreover, the transport of goods via rail offers very low unit prices which are another incentive for the market.[73]

[68] Cp. Rothengatter (2002), p. 29
[69] Examples are differences in gauges, power supply systems and non-interoperable railway signaling and protection systems. Cp. Rothengatter (2002), pp. 37ff.
[70] For example the labor market is already much more liberalized as it is possible for road transport carriers to simply hire drivers from other European countries with a lower demand in salary. Cp. Rothengatter (2002), p. 35
[71] Cp. Nagel (2008), p. 46
[72] Cp. Rothengatter (2002), p. 35
[73] Cp. Kummer (2006), p. 72

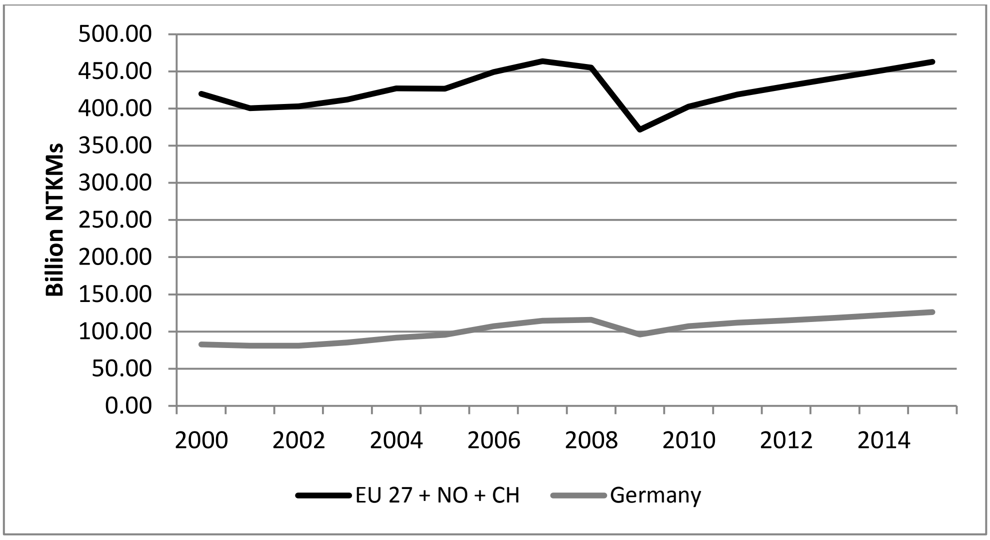

Figure 8: Development of the NTKMs by Rail[74]

Besides, there are efforts of the European Union to overcome the national differences. On the technical level, the interoperable network shall be achieved by means of the new Europe-wide standardized railroad control system ETCS. However, as this system is still at the beginning of its implementation, so far the non-stop border crossing transport are carried out by multi-system locomotives. The most significant measure taken to foster the market liberalization is the EU directive 91/440/EWG. It aims at the establishment of independent infrastructure providers in each country in order to allow non-discriminatory access to the national rail networks.[75] Unfortunately, the degree of implementation still differs from country to country, which is why the accomplishment of non-stop international transport services is still difficult, though the conditions are constantly improving.[76]

To conclude, the newest development of the railway sector is pointing out a positive future[77], especially when taking into account that the corrective measure taken on the European level will have an even bigger effect in future. This prospect also underlines the need for an improvement of the planning and steering processes in order to handle the increasing transport volumes efficiently, and if the goal is to fight back modal split shares from the road freight sector.

[74] Supplied by DB Mobility and Logistics AG and based on data from Federal Statistical Offices.
[75] Cp. Kummer (2006), p. 74
[76] Especially Germany, Sweden, England and the Netherlands can be considered as pioneers in this area. Cp. Busch (2002), pp. 39 and 49
[77] Cp. Rothengatter (2002), p. 37

4.2 The Rail-Bound Logistics System

The analysis and description of the rail-bound system will be subdivided according to a differentiation by input, inner-system processes and output.[78] While the input and output perspective reveals the required resources for the transportation process and the different end-products, the inner-system perspective explains the spatio-temporally combination of the resources within the production process.

Input factors of the Logistics System

The input factors that also will be considered in the resource planning are traction locomotives, freight wagons and infrastructure, in terms of track capacity. In addition, there are various other input factors that are relevant to the system. Even though they are not subject to the reference process model in particular, their consideration is important to the understanding of the system. Regarding the mentioned infrastructure above, loading and unloading facilities also play an important role.[79] Moreover, the railway production process requires human resources in terms of locomotive drivers, ground staff (e.g. for shunting and loading) and dispatchers who organize and supervise the operations. In the context of dispatching, a lot of information is required as input (e.g. time table and path information) also. Additionally, like every other production system, the railway system is in need of additives and operating supply items. Examples for additives are cooling water, oil or sand while operating supply items refer to the two different forms of energy, diesel and electricity. Eventually, the system also requires the goods that need to be transported. All goods that belong to the same client and have the same point of departure and destination are subsumed under the term *consignmen*t.

The input factors also can be differentiated by one's own resources and those that can, or have to be, rented. While the infrastructure represents a resource that is owned and planned by a third-party provider, locomotives and wagons can be both owned and rented. However, it depends on the special case if, or to which extend, a railway company carries out services with its own wagons and locomotives or with rented ones.

Output factors of the logistics system

The relevant output factors from the customer point of view are the (main) products, which make up the added value. In the context of the rail-freight sector a (main) product is not a physical item but the service of moving a particular consignment from point A (origin) to

[78] Cp. Westkämper (2006), pp. 195ff.
[79] Cp. Berndt (2001), p. 245

point B (destination) in the right time and with the right quality.[80] There are two product lines with different characteristic requirements towards the system. On the one hand, there are trainload transports (block trains) and, on the other hand, there are wagonload transports (single wagons). Formerly, less-than-wagon-load transports were offered, also, but due to missing cost-efficiency these transports have been ceased in most of the European countries.[81] Figure 9 illustrates the two current product lines and also the terminated less-than-wagon-load transports.

All **trainload transports** consist of only one consignment that has to be delivered from one single point of origin to one distinct destination. During the journey, no shunting takes place and, hence, the consignee takes over the train as composed by the consigner. A prerequisite for trainload services is a sufficient availability of transport volumes that can be combined to one consignment. In this case, these products come with many advantages for both the rail operator and the customer: minimal shunting efforts, short transport times, less complex organizational procedures and hence lower unit costs.[82]

On the contrary, **wagonload transports** comprise more than one consignment while at least one wagon is used by one distinct customer. At the point of origin, the customer hands over the wagon(s) to the rail operator who combines different consignments to one train in order to improve the resource utilization. However, as different wagons in one train have diverse destinations, this product requires conducting shunting activities in order to recompose the wagons at distinct stations.[83] Even though the related production processes (see below) are by far more complex than the handling of a block train, wagonload transports make up the majority of freight train movements across Europe.[84] Their biggest advantage can be seen in the greater flexibility for the customer who hands over a (smaller) consignment at one point and can expect it to arrive at the final destination within a pre-defined time frame, and also the wagon to be returned to the point of origin or any other station if preferred.

[80] Cp. Berndt (2001), p. 189 and Nagel (2008), p. 15
[81] Cp. Berndt (2001), pp. 18–22, Nagel (2008), pp. 38–41 and Fiedler (2005), pp. 363f.
[82] Cp. Berndt (2001), p. 19
[83] For a detailed description of the composing and re-composing shunting processes cp. Fiedler (2005), p. 366
[84] In Germany wagonload services account for about 60% of the transported volumes in the rail freight sector. Cp. Nagel (2008), p. 39

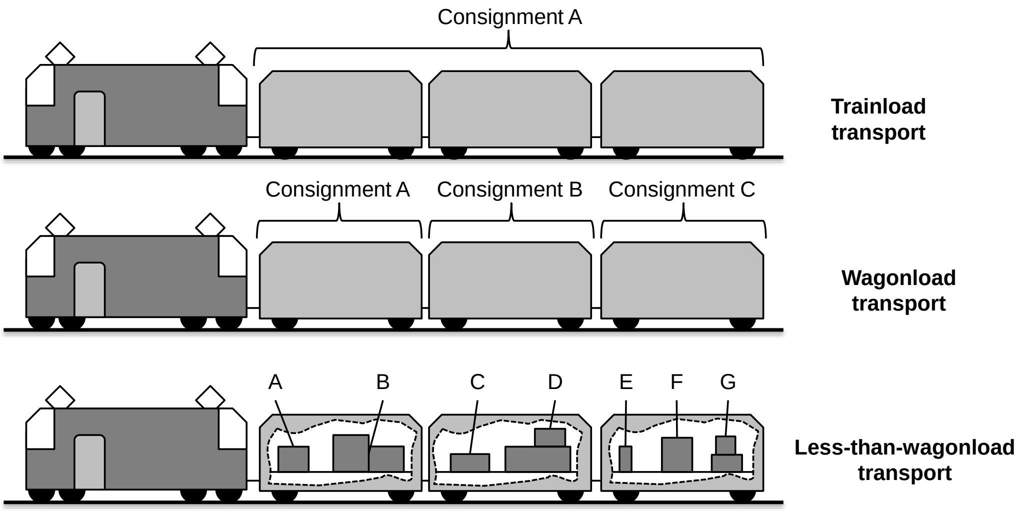

Figure 9: Railway Product Lines

In addition to the introduced (main) products, the logistics system emits side products such as exhaust or warmth. However, these objects can be neglected in the further course. Eventually, similar to the input side, various information flows occur that are relevant to both the rail operator (regarding operating conditions) and the customer (regarding the tracing of his consignment). This also shows that there is a lot of information that not only occurs at the end of the production process, but also in between. Therefore, a powerful information infrastructure is an additional prerequisite to every rail-bound logistics systems.[85]

Production Procedures of the Logistics System

The concrete production procedure within the rail-bound logistics system is based on two main system characteristics. First, there is the rail-bound or track-guiding character itself. Because of this, the system requires specific steering, controlling and securing elements on the technical level. The two main elements are switches, which allow to change from one track to another, and signals, which mainly regulate the distance between two trains.[86] Based on the rail-bound character, many authors also refer to the network character of the system. Nagel defines the rail network as a composition of links (edges) that are connected via nodes (vertices), whereas nodes also can be referred to as *terminal*s, a fixed place where freight is handled.[87]

Secondly, the system is characterized by long, breaking distances of the moving vehicles due to a low static friction between track and wheel. Hence, besides specific technical elements, particular rules of operation are also necessary. The most important

[85] Cp. Berndt (2001), pp. 190ff.
[86] Cp. Pachl (2008), p. 1
[87] Cp. Nagel (2008), p. 23

rule states that a train may only enter a section (also referred to as block section) between two signals when it is not occupied by other vehicles.[88]

Based on these two characteristics and the network character, further insights into the production procedure can be given. Fiedler introduces the flexible node-point system, which represents a specific structure of a railway network that can be found across most of the European countries (**Error! Reference source not found.**). In this context, each vertex fulfills specific tasks in terms bundling and dispersing consignments. In general, three different types of vertices can be identified:

a) Loading and unloading stations, also referred to as satellite stations
b) Junction stations in the remote areas of the railway network
c) Shunting stations with high capacities for re-composing trains

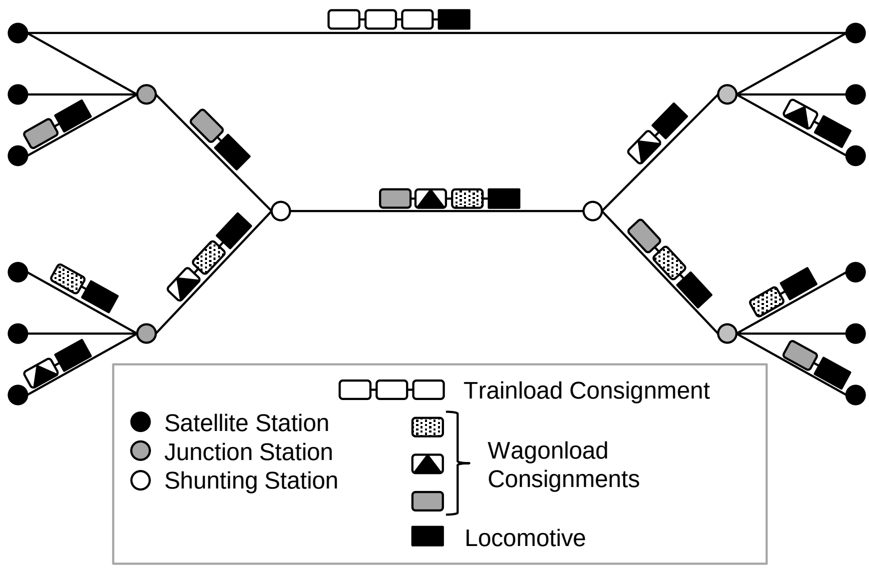

Figure 10 Flexible Node-Point System[89]

In the illustrated example, a wagonload consignment is running with up to four different trains until it reaches its final destination. This underlines, also, that wagonload services are crucial in terms of their planning. For each relation within the route, it has to be assured beforehand that the required infrastructure capacity and the hauling locomotive are available at the right time. Also, if the consignment shall be integrated into a longer train, the combination of wagons from different consignors has to happen in line with the time. Otherwise, a consignment might have to be put on hold until the relation is served the next time (given that there is free capacity).

[88] Cp. Pachl (2008), pp. 38ff.
[89] Based on Fiedler (2005), p. 365. However, as the illustrated network is a very abstract model of the real railway network, also block trains pass by different stations and use the same infrastructure as wagon-load transports. The direct horizontal line only indicates their non-stop character.

The infrastructure capacity plays a key role among all other regarded resources. Due to the EU directive 91/440/EWG (s. also 4.1), the planning and allocation of infrastructure capacity is handled by the national infrastructure provider. In this context, each edge in the network is subdivided into block sections, defined and regulated by signals. So-called *blocking tim*es within these block sections describe the temporal and spatial easement for one particular train. By combining these blocking times on a horizontal time axis for successional blocks in a cascaded way, complete train paths, from origin to destination, are created (Figure 11).

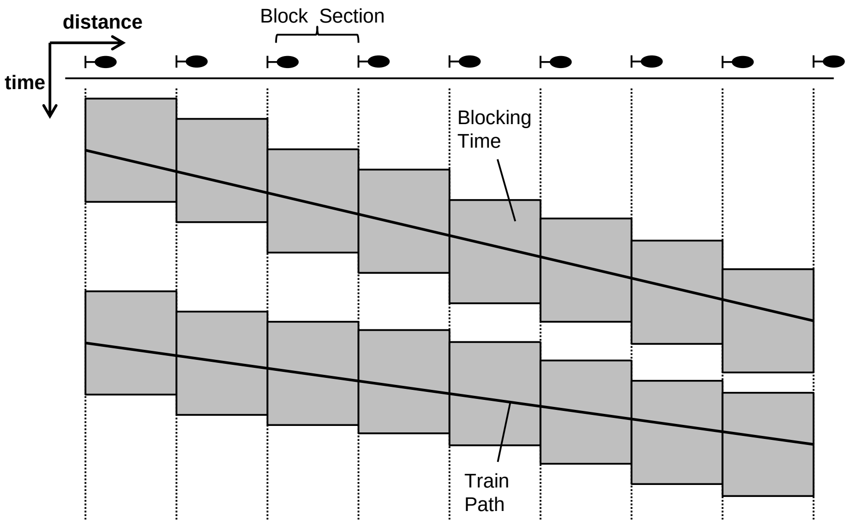

Figure 11: Block Times Combined to a Train Path[90]

The white fields in Figure 11 represent free network capacity. However, the infrastructure provider maintains a certain contingent of free capacity for compensating delays in traffic operation.[91] Moreover, it becomes obvious that different traffic patterns on the track may not be compatible. In the illustrated example, the second train is faster than the first one and will be delayed if it is not possible to switch the train order. Another issue that underlines the key role of the infrastructure capacity is competing path requests by different rail operators that cannot be served simultaneously because of overlapping blocking times. In that case, the path order procedure represents a negotiation process between rail operator and infrastructure provider.[92]

[90] Based on Pachl (2008), p. 52
[91] Cp. Pachl (2008), pp. 200f.
[92] Cp. Berndt (2001), pp. 249f.

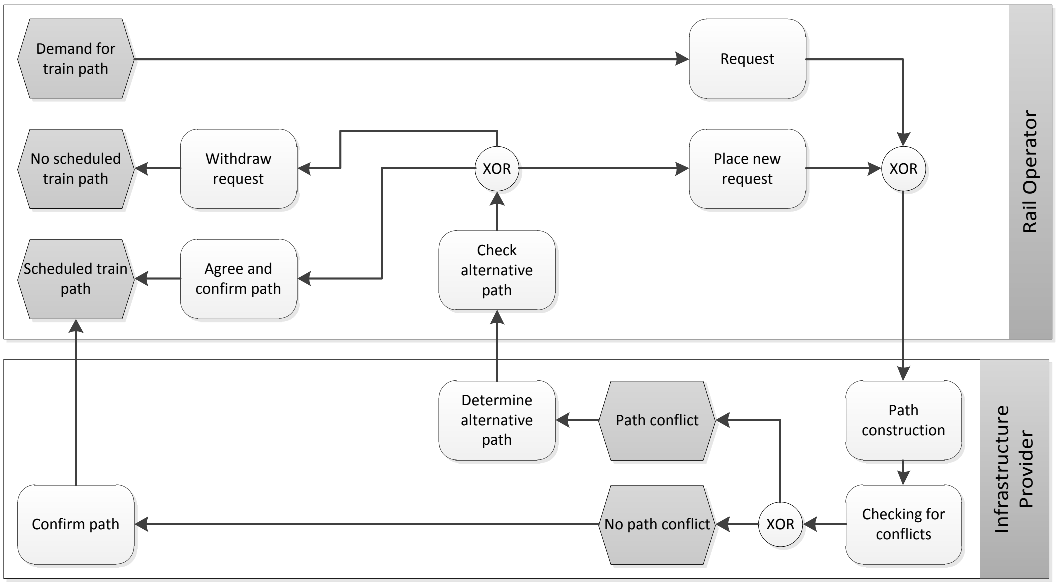

Figure 12: Train Path Ordering Procedure[93]

Figure 12 illustrates the train path order procedure. When the rail operator has a demand for a new train path, he places a request, which triggers the infrastructure provider to construct the requested path. Through visual and mathematical methods, the provider can determine whether there are conflicts with already-existing paths. If not, the request path is confirmed and the rail operator receives a schedule with all of the relevant information for operating on the requested path. But if there is a conflict, the provider offers an alternative path and opens the negotiation process. The operator evaluates then if the alternative path also suits his requirements. If it does, he will confirm the alternative path. If not, he can either place a new request or withdraw from the process. The EPC exemplifies, also, that this negotiation circle may not be solved with the first offered path alternative but rather represents an iterative process.

The infrastructure provider offers a portfolio of different paths that fall into:

a) Regular paths, usually ordered (many months) in advance
b) Short-term paths, ordered shortly before departure
c) Special paths, for trains with special requirements (e.g. excess width)[94]
d) International paths, coordinated by more than one infrastructure provider[95]

The paths differ very much in their planning horizons depending on the country. For example, in Germany a regular path has to be ordered by September 30 of the previous year[96], whereas in Romania a regular path can be ordered up until one day before departure. Additionally, it has to be taken into account that regular paths can be subject to

[93] Based on Berndt (2001), p. 250
[94] Will not be taken into account for the reference process model.
[95] Will not be taken into account for the reference process model.
[96] Cp. Berndt (2001), p. 248

both single orders (only one path is ordered) or long-term contracts that allow buying usage rights for a particular relation during a particular time of the day for several weeks or months.

4.3 Orders in the Rail-Bound Logistics System

After the rail-bound logistics system and its main product lines have been introduced, the focus turns to the transport orders and the connected resource allocation problem. A transport order is the link between the legal transport contract with the customer and the actual value-adding transportation process and post-production process activities, such as invoicing and controlling.[97] Depending on the order design, in each case there are different requirements on the logistics system.

Streichfuss undertakes an important characterization of the two product lines by differentiating between demand-driven and supply-driven business. In this context, the trainload transports represent the **demand-driven businesses,** as they comprise fixed and pre-defined relations. Orders are only accepted if the evaluation of the business case indicates profitability. Then a train schedule is set up and the block train operates according to the conditions of contract. On the contrary, wagonload services are referred to as **supply-driven businesses**. In order to offer a single wagon production system, the operator has to set up relations before he receives concrete orders. He has to establish a network that is capable of handling possible flows of consignments and, therefore, the rail operator alone has to take care of the utilization.[98]

From the legal point of view, one has to differ between two types of contracts. On the one hand, there are **individual contracts,** which refer only to one specific transport, such as one distinct block train run or a limited number of single wagon runs. However, these types of business relationships have become less important as the majority of transports is based on **master agreements**. The latter, on the other hand, refer to a longer periods of time, stating information about, for example, quantities, relations and conditions of operations within the regarded time frame. Furthermore, master agreements have to be differentiated according to their degree of flexibility. There are master agreements that state **fixed** dates and train parameters for each transport. And there are also agreements that are more **flexible**. For example, they may contain only an overall transport quantity, while the customer has the right to call up the concrete transport and place the concrete order shortly before departure. This also indicates that for flexible master agreements, from a legal point of view, concrete individual contracts still are required to initiate the order. In

[97] Cp. Berndt (2001), p. 200
[98] Cp. Streichfuss (2010), pp. 166–170

practice, the fixed and the flexible master agreement represent the two extremes of a continuum. In fact, it depends on each single business case which parameters are agreed on beforehand and which parameters are subject to short-term negotiations.

A combination of the introduced product lines, on the one hand, and the contract forms, on the other hand, leads to six different business case scenarios that provide the basis for the detailed resource allocation (Table 7). In the further course, a major differentiation between the two groups of business cases, i.e. A to C (trainload transports) and D to F (wagonload transports) seem reasonable. There are greater synergies within each group and fewer synergies between the main product lines due to the entirely different production concept.[99] However, collaboration between these two concepts could at least be based on a combined locomotive circulation planning.[100]

Table 7: Business Case Matrix

	Individual Contract	**Master Agreement**	
		Fixed Conditions	**Flexible** Conditions
Trainload Transport	Business Case **A**	Business Case **B**	Business Case **C**
Wagonload Transport	Business Case **D**	Business Case **E**	Business Case **F**

Based on the business cases, different planning horizons and modalities can be identified (Figure 13). Trainload services depend solely on the customer's demand. The planning horizons of this main product line fall into:

A) **Individual Contract**: Close to the starting point of the reference period, single block trains undergo a fixed planning. Within the reference period (shortly before departure) adjustments might occur, e.g. alternative routes or alternative traction.
B) **Fixed Master Agreement**: During the negotiation of the master agreements, fixed train schedules are established. Within the reference period (shortly before departure) adjustments might occur.
C) **Flexible Master Agreement**: Prior to the reference period, a pre-planning on the basis of approximate agreements takes place. The concrete scheduling happens shortly before departure, depending on the customer's call for a service.

On the contrary, after establishing the wagonload routes, single wagon transports come along with the following planning characteristics:

[99] E.g. usually wagon engaged in the single wagon system cannot be embedded in block trains. Cp. Berndt (2001), p. 222
[100] Cp. Berndt (2001), p. 237

D) **Individual Contract**: Slots can be allocated to different customers at each point of time as long as there is free capacity
E) **Fixed Master Agreement**: During the negotiation of the master agreements, slots within the reference period of the master agreement are allocated on the basis of a fixed schedule.
F) **Flexible Master Agreement**: Prior to the reference period of the master agreement, slots are allocated on basis of a pre-planning. According to the wishes of the customer, they can (partly) be re-scheduled later.

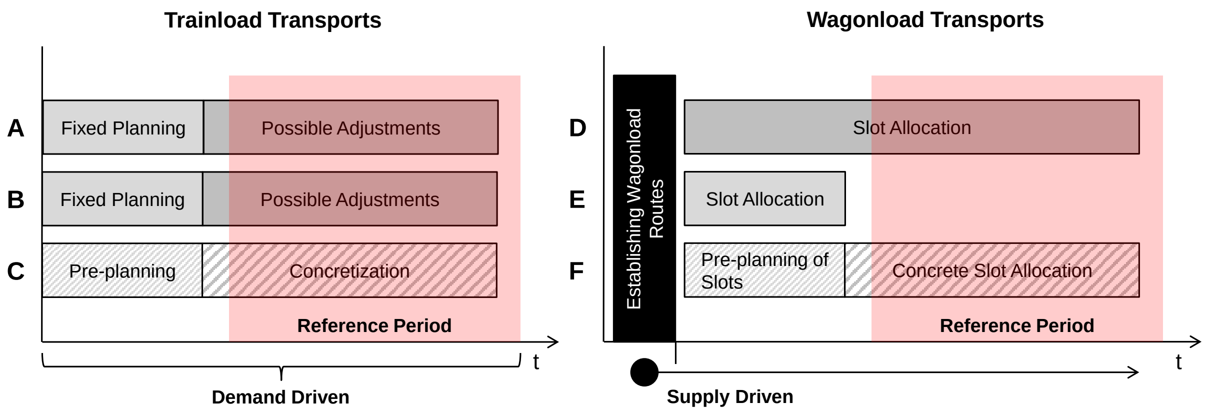

Figure 13: Planning Horizons Differentiated by Business Cases[101]

On the level of concrete business cases and orders, additional information is necessary to fully understand the resource planning. There are seven different parameters that are unique to every transport order. [102] The parameters are summarized in Table 8, which also states which resources (infrastructure, wagons or locomotives) are influenced by each parameter and which restrictions might occur during the resource allocation.

[101] However, the static image of Figure 13 should not imply that the planning procedure is also static. Rather, there is a continuous planning with a constantly moving reference period.
[102] Cp, Nagel (2008), p. 16

Table 8: Parameters of Transport Orders

Order Parameter	Effected Resource	Possible Restriction
Origin of transport	Infrastructure	• Origin not connected to network • Origin not served (single wagon system)
	Locomotive(s)	• No catenary for E-traction
Destination of transport	Infrastructure	• Origin not connected to network • Destination not served (single wagon system)
	Locomotive(s)	• No catenary for E-traction
Transport dates and times (including loading/unloading time)	Infrastructure	• No path available
	Locomotive(s)	• No locomotive(s) available
	Wagon(s)	• No wagon(s) available
Required transport Time	Infrastructure	• Speed limit of infrastructure
	Locomotive(s)	• Speed limit of locomotive(s)
	Wagon(s)	• Speed limit of wagon(s)
Type of good to be transported[103]	Wagon(s)	• Type of wagon(s) not suitable
Mass and volume of goods to be transported	Locomotive(s)	• Tractive force of locomotive too low
	Wagon(s)	• Loading dimensions too low • Number of available wagons too low
Required transport quality of good	Wagon(s)	• Equipment of wagons(s) not suitable

4.4 The Equivalent Production System

Based on the information on the logistics production system in sub-chapter 4.2, at this point the equivalent production system will be derived by means of the patterns from sub-chapter 3.2 and enhanced by arguments of the author. Previous to the application of the patterns, synonyms between both systems will form a basis for the transformation. In this context, especially, the following main elements of the logistics production system have to be assigned to an equivalent element in the production system: infrastructure in terms of distinct edges, locomotives, wagons, and, eventually, the transported goods. Further elements and terms will be transformed in Table 10.

The **infrastructure capacity** represents a special case as there are two synonyms, depending on the point of view on the resource planning. On the one hand, it can be associated with

[103] There are different types of goods (e.g. solid bulk goods, liquid bulk goods, containers or palletized goods) with diverse requirements toward the transportation process and especially the needed wagons. For a detailed classification s. Statistisches Bundesamt.

workplace capacity in the production. In that sense, each edge in the infrastructure represents a distinct production unit with a limited availability. Both elements have in common that they can handle only one order simultaneously and that their alignment forms a network.[104] This approach is relevant when planning the production capacity of the system, especially during the master planning and during the resource deployment phase. But the material requirement planning requires a different view on the infrastructure capacity. In this light, the infrastructure capacity has to be associated with **assembly parts** (i.e. **secondary demand**) that the product consists of. This alternative approach is discussed more in-depth when elaborating on the product composition in the transformation below.

Building on the first analogy about infrastructure capacity, **locomotives** and **wagons** are equivalent to **tools** that are used at the workplaces (e.g. a cutter or hammer). One peculiarity of locomotives as **active** tools is that they have a dynamic character because they are moving through the network. The locomotive moves from edge to edge. In this analogy, the tools in the production also would follow the material flow. Consequently, wagons, which are also moving along the edges of the railway network, can be seen as **passive** tools that support the material flow. This function equals **carrier mediums** (e.g. bins, boxes, pallets) in the conventional production.

Eventually, there also is an analogy between the **transported goods** in the rail-bound logistics system and the **raw material**s that undergo a physical transformation in the production system. With regard to the field of logistics, the added value from the customer perspective is the *spatial shift* of the goods. Similar to this, also in the physical production, the customer is not directly interested in material goods (such as cars or personal computers) but rather in the utility and benefit that they bring along.[105] The established synonyms and further analogies that are revealed throughout the following transformation are summarized in Table 10 at the end of this sub-chapter.

[104] The network character of the rail-bound logistics system has been introduced above. For the network character of production systems cp. e.g. Günther, Tempelmeier (2007), p. 2.
[105] Cp. Spengler, Dyckhoff (2010), p. 16

Table 9: Classification of the Rail-Bound Logistics System

	Criteria	Characteristics			
Output	**Character of main products**	Real assets production		Service production	
	Output type	(main) products		side products	
	Number of main products	Single product production		Multiple products production	
	Product composition	Multiple parts with complex structure	Multiple parts with simple structure	Single part	
	Criteria	**Characteristics**			
Process	**Number of connected production units**	Single-stage	Multiple-stage	Circular	
	Structure of material flow	Even	Convergent	Divergent	Regrouping
	Sequence flexibility	Flexible		Fixed	
	Continuity of material flow	Continuously		Discontinuous	
	Criteria	**Characteristics**			
Input	**Market desirability of input factors**	Production factors	Undesired factors	By-factors	
	Quality transformation during the process	Unchanged factors		Converted factors	
	Performance of unchanged factors	Active		Passive	
	Relation of converted factors to main products	Direct		Indirect	
	Availability of input factors	External factors		Internal factors	
	Split of input factors	Material intensive	Equipment intensive	Labor intensive	Information intensive

Starting now, with the transformation according to the introduced patterns, the focus shifts to Table 9**,** which classifies the rail-bound logistics systems accordingly. It starts with the output perspective. As no physical transformation takes place, the **service character of the production** system is obvious. Because the side products of the systems (e.g. exhaust or warmth) are not relevant to this work, it is sufficient to assume that the system emits only main products (wagonload and trainload transports). The differentiation between wagonload and trainload transports, and the fact that (from a detailed perspective) every relation in the production system represents a different product, leads to the classification as a **multiple products production**. Moreover, defining each process step (e.g. a train run on a distinct edge) as a part of the final product classifies the output of the rail-bound logistics system as a **multiple parts product**. However, as there is not a very high number of process steps (e.g. compared to the nearly infinite number of product components in the shipbuilding industry, etc.), the structure is still **simple**.

Proceeding with process criteria, the rail-bound logistics network resembles a **multi-stage** and **circular production** network. This can be explained by the various connected edges that have already been defined as workplaces (stages). As the rail production concept also requires bringing (empty) wagons and locomotives back the destination of origin – in case further transports on this relation are carried out – the circular character becomes obvious. Moreover, the material flow is either **even** (in case of trainload transports) or **regrouping** due to the shunting activities of the wagonload services (cp. also **Error! Reference source not found.**). On a first view, the **sequence** of production processes could be considered as flexible, as, for example, alternative routes allow deviation from a certain pre-defined route. However, as on one distinct route, the order in which the edges are combined cannot change, the sequence is **fixed**. Eventually, the **material flow** is mostly discontinuous, even though a running train partly resembles a continuous flow. But in the long run, it becomes obvious that a train will have to stop several times (at signals or for re-composing purposes) before it reaches its final destination. Therefore, the output frequency of the system has to be considered **discontinuous**.

On the input-side, there are only **production factors** and no undesired factors or by-factors. With regard to their transformation, both cases apply to the system: On the one hand, there are **unchanged** factors (locomotives, wagons and infrastructure) and ,on the other hand, there are **converted** factors (e.g. diesel that is combusted and emitted as exhaust). As already elaborated above, in this context locomotives, for example, represent **active** factors, while wagons represent **passive** factors. The converted factors are only **indirectly connected** to the main product as the example with the diesel shows. Additionally, the fact that the main product is a service (see above) that cannot be directly related to physical components underlines this finding. Evaluating the input factors against their availability reveals both **external** and **internal factors**. For example, wagons and locomotives that belong to the property of the rail operator are internal factors. And the infrastructure capacity and, in a wider sense, rented locomotives and wagons are external factors. Finally, the question of which input factors have the biggest impact leads to **equipment** and **information**. The rail-bound logistics system can be considered as equipment-intensive due to the high capital expenditures for locomotives and wagons. The importance of an efficient information infrastructure to handle to the extensive flow of information has already been introduced above.

Table 10: Production Dictionary for Railway Terms

Railway Term	Equivalent Term
Infrastructure capacity	A) **Machine or workplace capacity**, because of the network character of the rail-bound logistics system and the limited availability of the edges that represent the production capacities. Below this perspective also will be referred to as **workplace view**. B) **Assembly parts**, because a product in the rail-bound is produced in multiple steps by combining (assembling) the infrastructure capacity in the right order. Below this perspective also will be referred to as **assembly view**.
Locomotives	Associated with **active tools** due to their dynamic character. They move along the edges (different workplaces) and add a certain value to the production process by bringing the production process forward.
Wagons	Similar to locomotives, wagons are also **tools** but with a **passive character,** as it is their main function to carry the goods through the network. They are not actively involved in the value adding process. From a more concrete point of view they represent simple **carrier mediums**.
Transported goods	Equal to **raw material**s, which also undergo a value-adding process in the classical production network.
Shunting	Referred to as **set-up activity**, because shunting also is a secondary activity that does not directly contribute to the value-adding process of the traction business.
Infrastructure provider	Referred to as **control center**, because the task of the infrastructure provider is nothing other than the centralized distribution of scare resources to different production units.
Product	A **served relation** in the railway network **from origin to destination**.
Train paths	In the light of the assembly view (see above), the single train paths can be associated with assembly parts (i.e. secondary demand) the product consists of. This secondary demand is documented in the **item list**. Consequently, the single assembly parts can be derived through a bill explosion.

4.5 Equivalent Orders in the Production System

There are three criteria of the order fulfillment process that can be used to describe the character of orders: relation to market, order initiation and lot size. Based on this, the orders within the rail-bound system are classified below in Table 11.

In order to identify the relation to market, the differentiation between demand- and supply-driven businesses (see p. 36) can be used. On the one hand, trainload transports (demand-driven) resemble an **assemble-to-order production** with a comparatively high degree of customer influence. The non-customized manufacturing can be seen in standardized production, as there are only a few, or no alternative routes in the railway network. However, one could argue that there is still a high degree of customer influence in terms how the train is comprised and which wagons are used and, hence, subsume trainload transports under the term make-to-order production. But as the key aspect of the rail-bound logistics system is the resource allocation problem (i.e. to assemble), to refer to an assemble-to-order production seems to be more appropriate here. On the other hand, when referring to wagonload services, a **make-to-stock production** is the closest equivalent, as it suits the description of a supply-driven business. The products on stock are equivalent to the already-established wagonload routes. However, there is a difference in that in the rail-bound logistics, because the actual production has still not been carried (even though the resources are committed).[106] Therefore, for the modeling of the production system, fictitious products on stock that still need to be produced but are already promised to the customer can be seen as an analogy. In this vein, another characteristic of the orders in the rail-bound (regarding both ATO and MTS products) is that the finished products are not superposable. Therefore, the production cannot be carried out at an earlier point in time but has to be exactly in line with the production schedule and customer demand.

The order initiation in the rail-bound logistics is based either on individual contracts or master agreements. Therefore, the classification of the second criterion is simple, as individual contracts also can be referred to as **single orders,** while **master agreements** directly match with Table 11. However, it has to be kept in mind that in the rail-bound logistics, an additional single order contract also is necessary to initiate certain services from the (flexible) master agreement.

If applying the lot-size criterion, the orders in the rail-bound logistics system are referring to a **single production**. In sub-chapter 3.2, a lot was defined as a set of equal products that are produced successionally. Taking into account that a train or a wagon (i.e. a distinct product) is usually followed by another train or wagon that does not belong to the same product, or even does not belong to the same rail operator, leads to the understanding of a single production in the rail-bound logistics system.[107]

[106] Therefore, the railway system benefits from a certain degree of freedom in their make-to-stock production as in some cases relations can still be cancelled.

[107] Different from the product perspective which is used here, often the term lot-size is also associated with the mass and volume of the transported goods (cp. Nagel (2008), p. 16.

Table 11: Classification of the Orders in the Rail-Bound Logistics System

	Criteria	Characteristics			
Output	**Relation to market**	PTO	MTO	ATO	MTS
	Order initiation	Master agreement	Single order	MTS	
	Criteria	Characteristics			
Process	**Lot size**	Single production	Batch production	Mass production	

4.6 The Specific Order Fulfillment Process

The transformation in this chapter reveals various requirements of an equivalent order fulfillment process in the context of a production company. The classification of the logistics system by means of the patterns, especially, but also the initial description of the logistics system and its orders, offer valuable clues on how to set up the reference process model. Therefore, a summary of the key requirements and interpretation of the findings above, closes this chapter. From this point on, the wording refers only to the production -elated terminology, as the reference process model also will be set up in this language.

The transformed production system has to deal with various input factors that underlie numerous restrictions and, additionally, are not fully internally controllable. The most obvious example is the centralized allocation of the machine capacity. Additionally, the order of production is mostly fixed, which points out the high importance of the planning activities in the order fulfillment process. The high level of influence of external players (the control center) has to be compensated by a holistic effective resource planning.

The question now is what the proposition, or the overall guideline, for the resource planning in the production should be. Two transformation criteria shed light on this question. First, due to its lot sizes, the present system represents a single-production system. Hence, a lot of set-up activities will be required. Second, the production is very equipment-intensive due to the high acquisition costs of the deployed (active and passive) tools, respectively carrier mediums. Combining these two arguments leads to the conclusion that it should be the primary target to reduce capital lockup costs by minimizing the set-up activities. Therefore, the tool circulation circulation planning is the key to an efficient production system. In this light, an optimization of the order fulfillment process also can be achieved by combining certain production processes (e.g. the backhaul of the tools and carrier mediums and the actual production or combining two products on one machine if possible) and, hence, making use of scale effects.

It also has been outlined that there is only one production infrastructure that is not only shared by different production entities, but also is used to produce various products with different prerequisites. This leads to the requirement to differentiate within the planning according to the specific business cases, on the one hand, but, on the other hand, not to have an isolated view on each business case. If each planning module (within each business case) operates independently, no holistic capacity planning and no scale effects can be realized. In addition to the approach to use connected planning modules, there must be the possibility of customizing. The example with the different time horizons with regard to machine capacity ordering (difference of 6 months to a few days) showed that the order fulfillment process has to be kept flexible and adjustable, according to the (national) peculiarities of the production companies.

Regarding the resource deployment planning or, in particular, the workplace capacity allocation plan, the equivalent order fulfillment process shows another particularity. In sub-chapter 4.4 it has been explained that the active tools and carrier mediums have to be returned or forwarded to the point in the production system where they are required next. As these backhauls also make use of the production infrastructure, they have to be included in the workplace capacity allocation plan. Moreover, these backhauls also could be considered as additional set-up times of the workplaces.

The necessity to keep the different planning closely connected is underlined by the information-intensive character of the production system. It is important that each organizational unit or person who is involved in the planning process is well informed about the current planning status. Therefore, a powerful information infrastructure in terms of centralized and unique software should facilitate the order fulfillment process.

Eventually, the order fulfillment process requires consideration of make-or-buy decisions. On the one hand, this is especially important as the deployed assets are very expensive in their acquisition. Therefore, especially for short-term requests that exceed the own production capacity, renting of tools should be considered. On the other hand, it is quite likely that for some requested services by the customer the production network is not sufficiently equipped. In that case, it might be an advantage not to refuse the request but to take into account the purchase of certain product components in order to still be able to offer a complete product to the customer.

5 Development of the Reference Process Model

This chapters deals with the construction of the reference process model for rail-bound logistics (step 6), according to the meta development model (Figure 1). The initial point of construction is provided by the previous transformation, which facilitates the creation of the model by means of a production terminology. Moreover, the input is taken from the sources that have been introduced in chapter 2.

As throughout the course of this work, different presumptions have been made and certain views and elements have been excluded from the model, in a first step the scope of the model will be summarized again (5.1). Additionally, the present reference process model will be classified according to the criteria of information models that have been introduced at the beginning of this work (5.2). Subsequently, the actual development takes place, divided into two parts: While in part 5.3 the main structure (i.e. the architecture) is developed, in part 5.4 the detailed process descriptions are presented and explained to the user. This chapter closes with a summary of requirements for standard production software that would be suitable to cover the workflow of the presented process chains (5.5).

5.1 Scope of the Reference Process Model

In the previous chapter, various assumptions have been made to prepare the rail-bound logistics system for the development of a suitable reference process model. These assumptions, and further facts, necessary to define the scope of the model are summarized below:

- The model only refers to the operational resource planning (cp. p. 1). Therefore the planning horizon comprises approximately one year.
- The model has a system boundary that is clearly circumscribed by incoming orders, on the one hand, and the completion of the product on the other (cp. p. 10). This also means that tendering processes will not be covered by the model.
- The regarded resources are: machines (infrastructure capacity), active tools (locomotives) and passive tools (wagons) (cp. 28f.). Hence resources and tertiary demand are not part of the modeled resource planning.
- Solely main products are relevant to the model as the view on side-products is excluded (cp. p. 29).
- With regard to the machine respectively infrastructure capacity, only regular paths and short-term path are subject to the model (cp. p. 33 f.). Special and international paths are excluded

5.2 Classification of the Present Reference Process Model

The present reference model, which will be developed later, has the following specific characteristics as stated in Table 12. This table also is analogue to the one presented in chapter 2.1. The dark grey shaded cells mark the characteristics of the particular reference process model of this work.

Table 12: Attributes of the Present Reference Process Model[108]

Attribute	Characteristics		
View	Structure view		Behavior view
Claim to validity	Actual state model		Ideal model
Level of description	Functional concept	IT concept	Implementation
Range of applicability	Company model	Inner domain	Cross domain
Target group	Application model		Organization model
Degree of abstraction	Specific model		Type model
Level of the modeling language	Object model		Meta model

With regard to the view, it has already been explained that the **behavior view** subsumes the process character. Because all reference process models have to be **ideal models** in order to be distinguished from information models, the second criterion is trivial. On the contrary, with regard to the level of description, various options exist to set up a reference process model. As the model in this work will contain only business-specific knowledge without a detailed guideline for implementation or IT-based description, it has to be considered as a **functional concept**. Moreover, the reference process model of this work is meant to be valid only for users within the domain of the rail-bound logistics and, hence, has an **inner domain** character. Similar to this attribute, the present model also will be developed for the purpose of process implementation and optimization and, consequently, represents an **application model**. Again, with regard to the degree of abstraction, the only existing option for the reference process model is to be designed on a more abstract level and, thus, as a **type model**. Eventually, the level of the modeling language needs to be defined. Although this work also will make use of existing models, most of the parts will refer directly to the object of modelling (i.e. the resource planning process). Therefore, this work is subject to **object modelling**.

[108] Cp. Schwegmann (1999), pp. 53–55, Kallenberg (2002), pp. 25–28 and Schütte (1998), pp. 63–74.

5.3 Basic Framework and Architecture – Level 1

In order to facilitate reusability, customizability and user-friendliness, the reference process model consists of different planning modules that are connected to each other. Additionally, the model comprises two levels of different granularity. The first level (i.e. the reference process model architecture) illustrates the arrangement of the planning modules. The second level of the model contains the detailed process description for each planning module (s. 5.4).

The architecture of the reference process model follows a two-dimensional matrix structure. One dimension describes the business cases that have been introduced in chapter 4.3. The other dimension contains the different planning modules (from order acceptance to production monitoring) that have been identified by means of specialist literature in chapter 3.1. In this way, modules for each business case are created in the overlapping sections of the matrix (Figure 14). Each grey, shaded, overlapping area represents a distinct planning module of the reference process model.

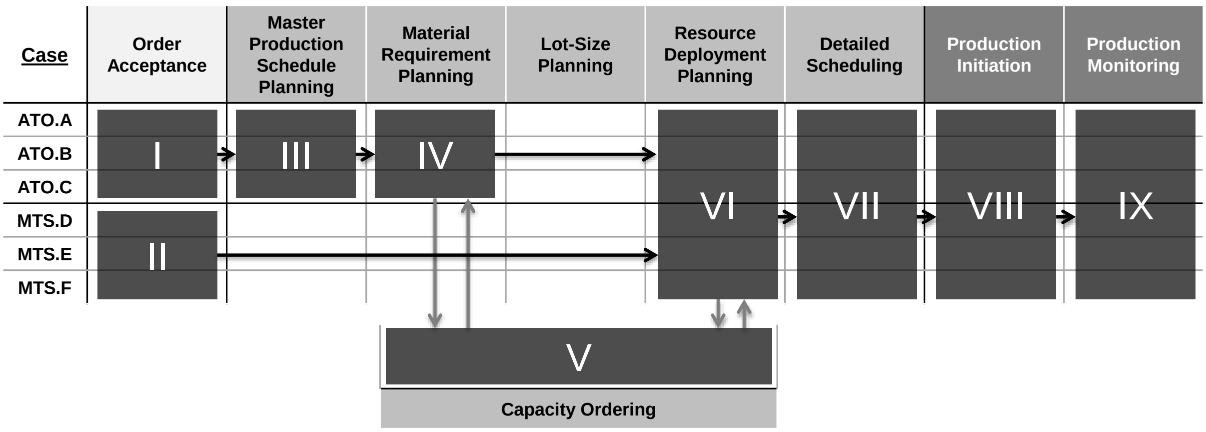

Figure 14: First Level and Architecture of the Reference Process Model

It was the approach to cover as many business cases as possible with one module in order to achieve planning synergies and to reduce redundancies. However, for the order acceptance module it was necessary to differentiate between ATO and MTS production as the MTS business cases require much simpler process descriptions. With regard to the master production schedule planning and the material requirements planning, there are only planning modules for ATO business cases. For the MTS cases, these modules are not relevant from the perspective of the operational resource planning, as the gross planning of resources and materials belongs to the product design phase prior to the order acceptance (supply-driven business cases). Another peculiarity of this reference model is that there is no module for lot-size planning. During the transformation, it has been explained that the production system can only generate single-unit lot-sizes and, so, there is no need for such a planning module. From the resource deployment on, both business case types (ATO and MTS) have combined planning modules. Practically, from this point on, it is not relevant anymore how the production process was triggered when it comes to the detailed resource planning and the execution of the production.

Eventually, there is also one model outside of the matrix that covers the capacity ordering. It contains the process descriptions that would have been redundant in the material requirement and the resource deployment planning module. In both modules, it is necessary to address the possibility of ordering workplace capacity at the control center.

5.4 Detailed Process Descriptions – Level 2

5.4.1 Order Acceptance for ATO Production (I)

According to the reference model architecture above, the first planning module refers to the order acceptance of all ATO business cases. The process description can be found below in Figure 15.[109]

The trigger of the entire process chain is the customer request for an ATO product. Subsequently, the feasibility and the reliability check are carried out simultaneously. The feasibility check examines, from the technical point of view, if the internal production facilities are sufficient to fulfill the order specifications. Either the production entity has all required tools at its disposal and is equipped with suitable workplaces (workplace view), or it has to consider the deployment of external resources. Here, both cases might occur: The renting of active and passive tools and the (partly) external processing of orders. In the latter case, production steps that cannot be carried out due to missing suitable workplaces in the production network are carried out by another production entity. After this check, it has to be decided if the order is feasible by means of external resources, or if it is still impossible to fulfill the customer specifications. If the order is still not feasible, the customer request has to be rejected. On the contrary, if the deployment of external resources would make it possible to fulfill the customer request, or if the order is feasible with own resources, only the process continues with the CTP check.

However, before proceeding with the CTP check it needs to be ensured (in the reliability check simultaneously to the feasibility check) that the customer is a reliable business partner. If the customer is known from former business relations he can be evaluated based on past data (e.g. cash flow). If not, he needs to be evaluated based on information available to the public only, such as his reputation in the media. The result of this sub-module can either be that the customer is unreliable, which leads to a rejection of his request, or that he is reliable, which triggers the CTP check.

If the CTP check has been triggered by both, a feasible order and a reliable customer, it is checked whether the order is accomplishable from the capacity perspective. At this point, it comes to a differentiation between active and passive tools. For both tool types it is checked on a highly aggregated level whether enough capacity will be available without taking down- or set-up-times into account. In case the capacity seems insufficient, there is still the possibility to rent the missing tools and substitute the missing capacity. At this point, information about rental costs is very important because subsequent to the CTP check, the

[109] For this module, no other reference process models from literature could deliver valuable input. Therefore, the process descriptions of this part are solely based on the theoretical findings of the order fulfillment process and the transformation.

profitability check approves the economic efficiency. But if the business case appears to be unprofitable, the initial plan needs to be changed. By entering another negotiation round with the customer, either a new contribution margin or an alternative production concept (which promises a revenue surplus) can be agreed on. But also the rejection of the customer request, if no common agreement with the customer can be achieved, is possible.

If the business case has been (finally) classified as profitable, a binding offer can be placed to the customer. As most likely he still has not signed any legal contract so far, he could still resign from his request. But if he signs and agrees to the offer, the aggregated tool capacities are updated and the order is added to the sales plan for ATO products. Subsequently, the process continues in the master production schedule planning module (5.4.3).

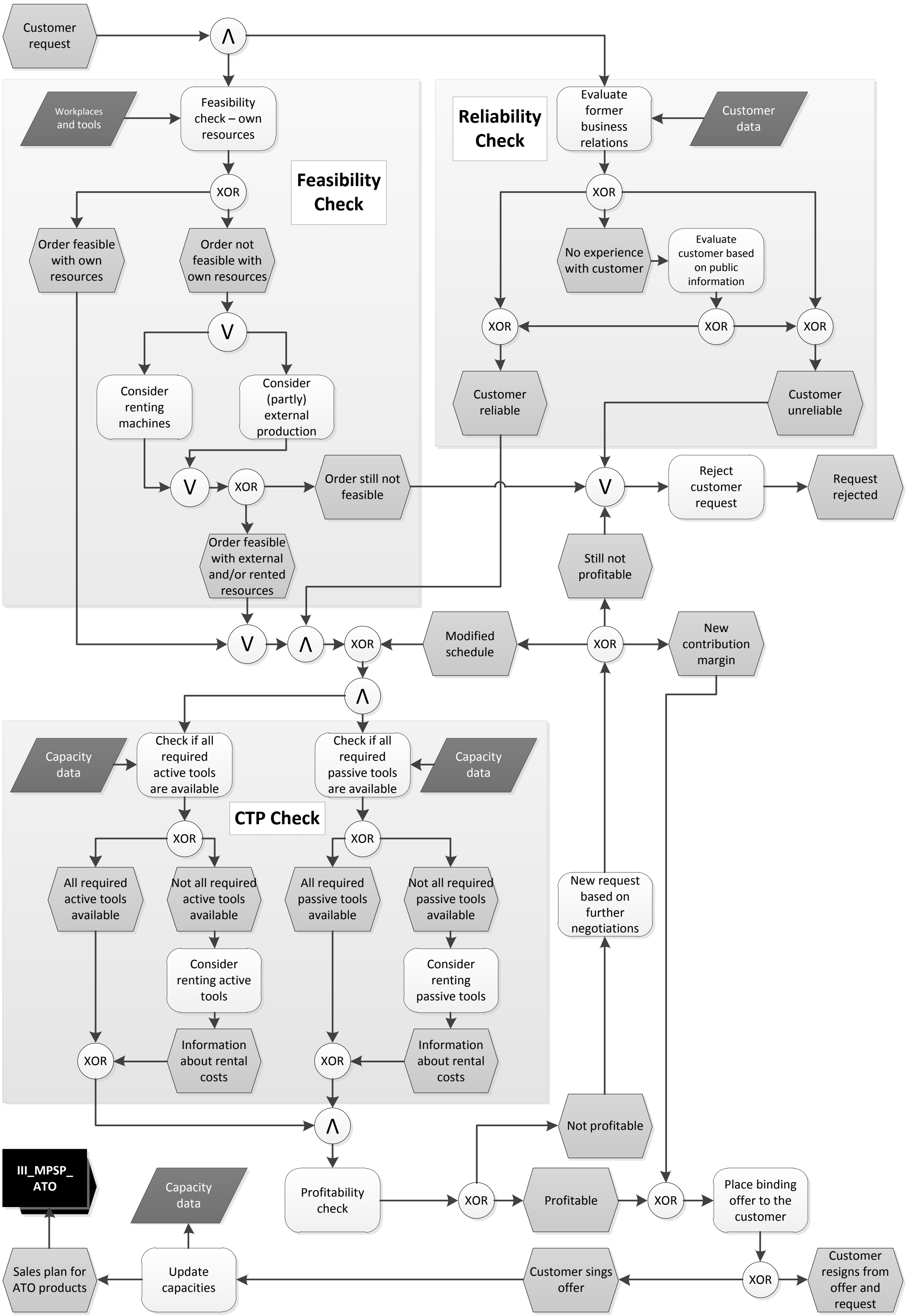

Figure 15: EPC for the Order Acceptance in the ATO Production

5.4.2 Order Acceptance for MTS Production (II)

The order acceptance process for MTS products represents the second starting point for the entire reference process model. Also, here the customer request is the trigger for the following process steps. The only difference from the ATO acceptance process chain is the reduced complexity. Otherwise, all remaining functions and events are similar, which is why the description of the above ATO acceptance process also can be applied here. Nevertheless, the decision was made to illustrate this module separately from the previous one, as it is easier to read when hiding unnecessary process steps. The process is illustrated by Figure 16.[110]

[110] For this module, no other reference process models from literature could deliver valuable input. Therefore, the process descriptions of this part are solely based on the theoretical findings of the order fulfillment process and the transformation.

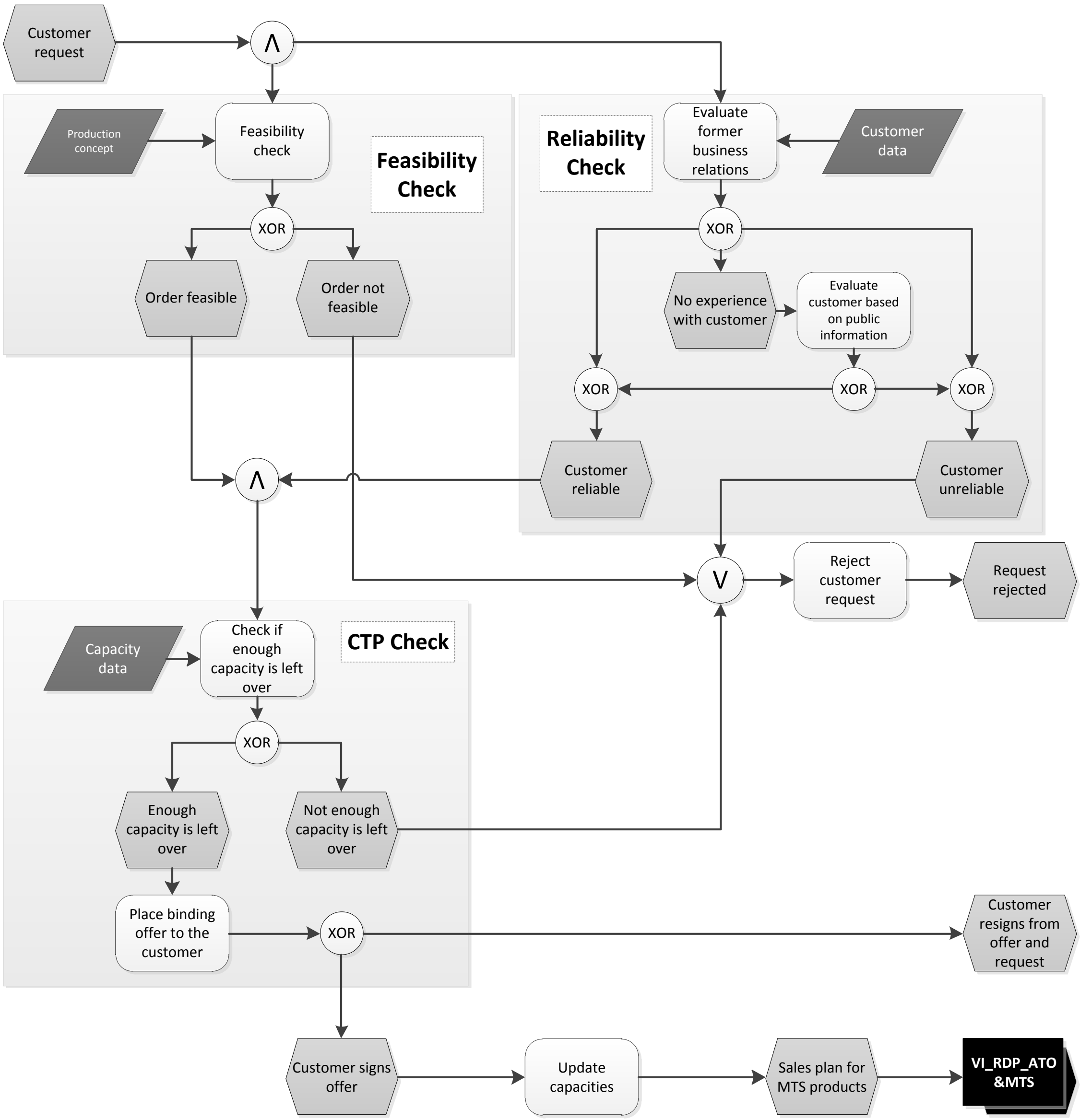

Figure 16: EPC for the Order Acceptance in the MTS Production

5.4.3 Master Production Schedule Planning for ATO Production (III)

The third module covers the master production schedule planning for the ATO production (Figure 17).[111] As already introduced above, there is no analogue module for the MTS production, as the gross planning for MTS products in this particular production system take place prior to the order acceptance.

This module is either trigger by the sales plan for ATO products as a result of the first module (5.4.1), or from the sales forecast. Besides the short-term orders, the sales forecast also contains assumptions about the concrete dates of the flexible master agreements, which are still not fully scheduled from the customer side. In a first step, these two aggregated input sources have to be broken down to defined periods and the exact number of products that are supposed to be produced in these periods. Subsequently, the next two functions focus on the tool capacity calculation. First, it has to be determined how many and which types of tools are required for each product. This approach already reveals more details than the previous CTP check. However, it still has not been decided which unique tools to deploy, but only the type of tools. When the type of tools and the required numbers have been determined, a gross planning of the required capacity follows. This is done by adding up the actual production times for all products in that period and multiplying it by the number of required tools. The set-up times (which are mainly due to the backhaul of the tools) are added only as an average surplus at this point.[112]

Table 13: Capacity Matrix in the Master Production Schedule Planning

	Period T_i			Period T_j		
	Demand	Limit		Demand	Limit	
Tool type y	8	10	✓	12	12	✓
Tool type z	17	20	✓	22	20	✗

A simple instrument for the next step, which compares the required capacity with the available capacity, is the illustration by means of a two-dimensional table (Table 13). As long as the demand is below the maximum limit, the tool capacity is sufficient. In this case, the master production schedule can be set up for that particular period and the order fulfillment procedure continuous with the material requirement planning (5.4.4).
But in case of insufficient tool capacity (cp. tool type z in period T_j), it has to be evaluated whether some of the orders could be shifted to other periods without violating the sales

[111] For this module all three potential sources have been taken into consideration. In particular Keller, Teufel (1999), pp. 298–316 , Mertens (2009), pp. 127–130 and Scheer (1997), pp. 96–102.
[112] Cp. Mertens (2009), p. 144

plan and causing delays in the production. If a shift is not possible, the process flow leads back to the acceptance module with the request to revise the sales plan (which could also include rejecting initially accepted orders).

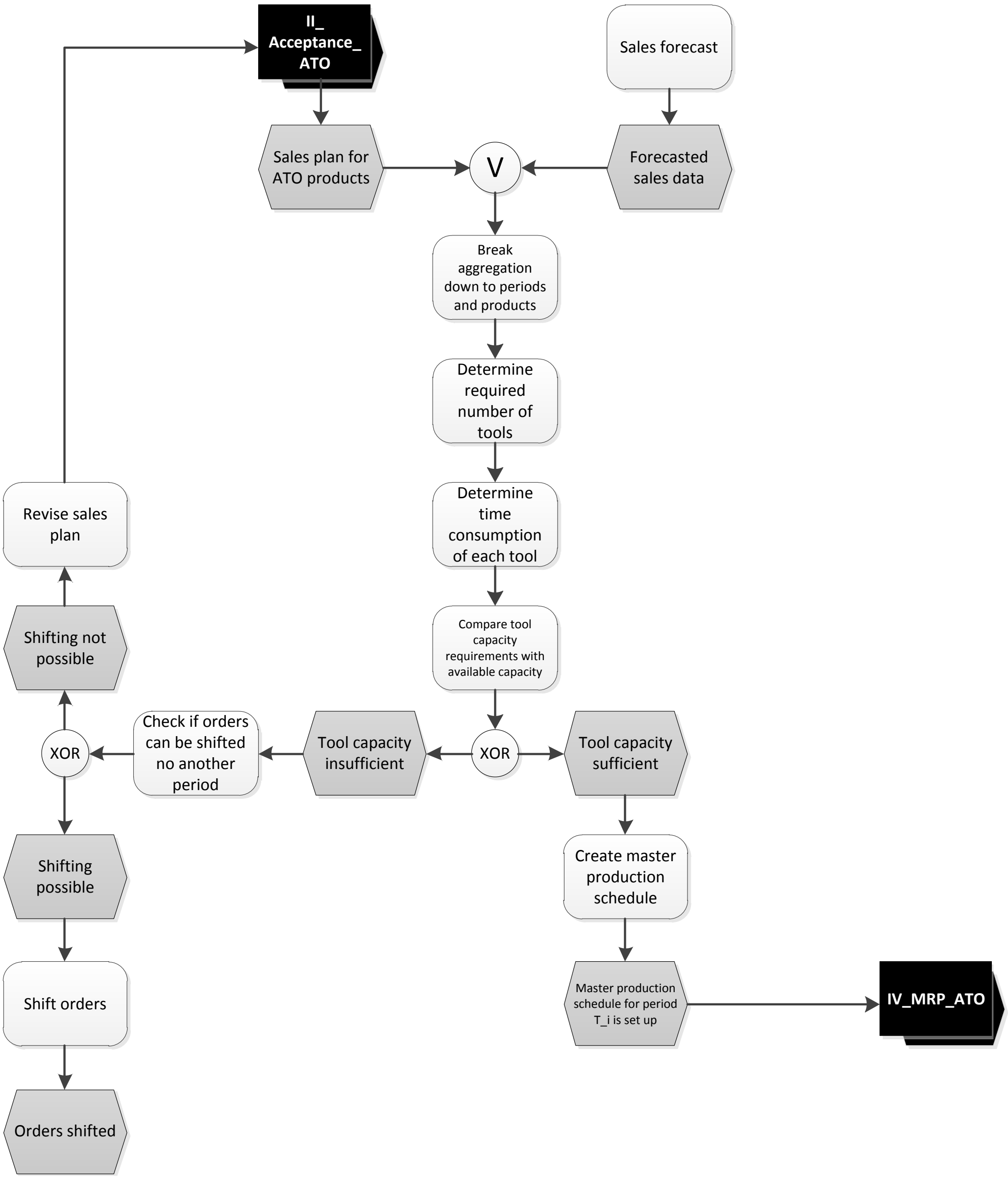

Figure 17: EPC for the Master Production Schedule Planning in the ATO Production

5.4.4 Material Requirement Planning for ATO Production (IV)

Once the master production schedule is set up for a particular period, the material requirement planning can be carried out (Figure 18).[113] This module, as well as the following module for the resource deployment planning (5.4.6), is special as it also includes the second analogy for the infrastructure capacity. So far, only the workplace view has been applied, but in order to derive the necessary workplace capacity from the production plan, the infrastructure capacity has to be perceived as secondary demand, i.e. the assembly view. This module also refers to the ATO production only.

Starting with the assembly view, the first step of this module is to conduct the bill explosion based on the item list. The aim is to derive the assembly parts of each product and, thus, the secondary demand. After that, in the context of the secondary demand a differentiation should be made between third-party production and own production. On the one hand, an order needs to be placed at the aspired external production entity for assembly parts that are supposed to be purchased from external sources. On the other hand, for assembly parts that are planned to be produced internally, the associated workplace capacity needs to be ordered at the control center. With the capacity ordering, the focus switches back from the assembly view to the workplace view. However, the capacity ordering procedure forms an independent, reusable module (s. 5.4.5).

With the confirmed third-party production orders and the saved workplace capacity (after applying module V), the production plan can be updated and the process continues with the subsequent module, the resource deployment panning (5.4.6).

[113] For this module all three potential sources have been taken into consideration. In particular Keller, Teufel (1999), pp. 476–495 , Mertens (2009), pp. 131–139 and Scheer (1997), pp. 105-148, 182f..

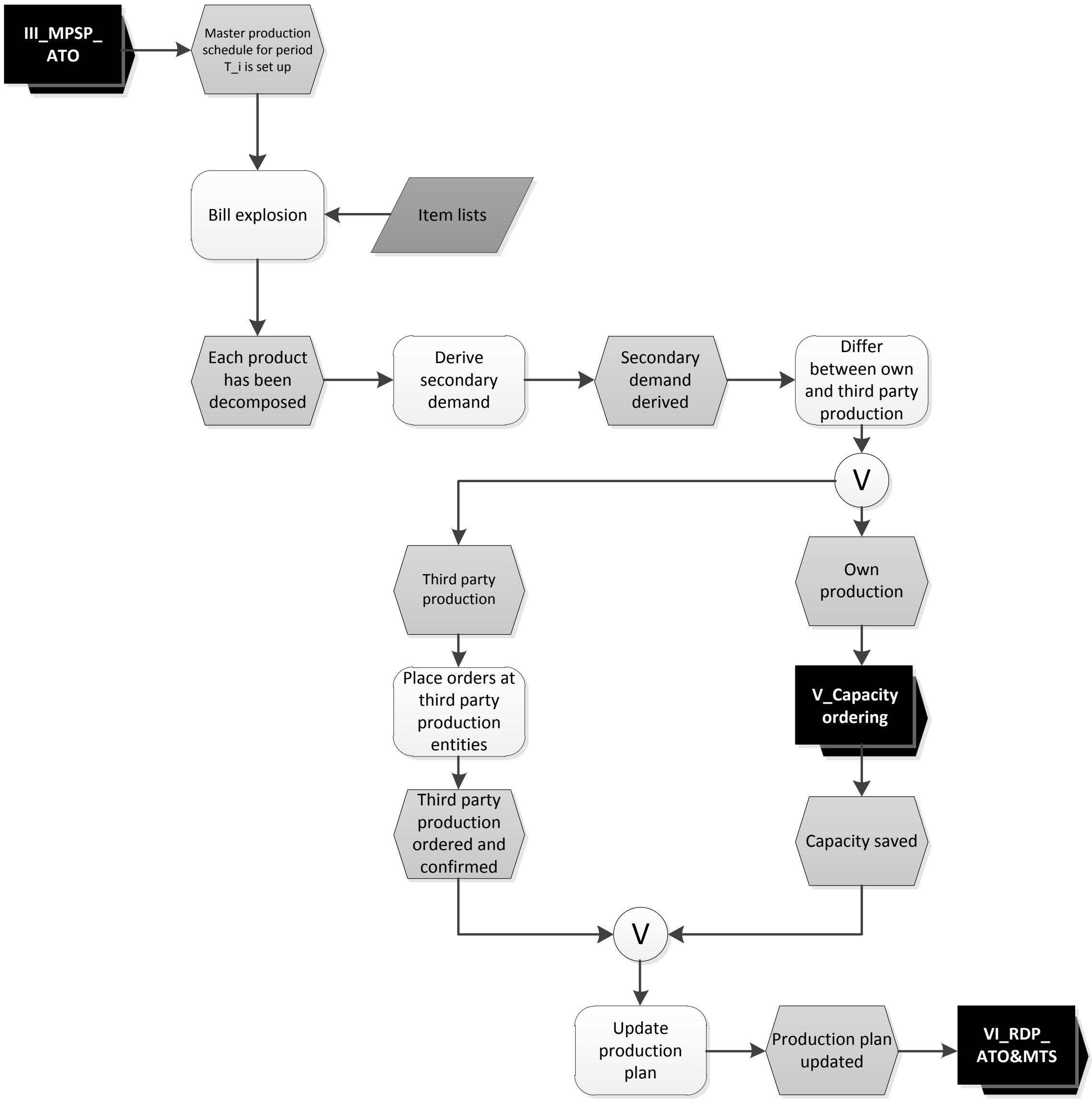

Figure 18: EPC for the Material Requirement Planning in the ATO Production

5.4.5 Capacity Ordering (V)

According to the theoretical findings on the order fulfillment process, the capacity ordering is not a separate module in particular. However, in this reference process model it makes sense to isolate the capacity ordering procedure, as it occurs at least twice in the exact same manner: Once in the material requirement planning (5.4.4) and once in the resource deployment planning (5.4.6). The EPC for the capacity ordering procedure is illustrated in Figure 19.[114]

If there is the need for future workplace capacity, a request is placed at the control center. Consequently, two possible results may follow. Either, the request suits the capacity allocation planning of the control center and a confirmation follows right away, which leads to an internal saving of the capacity slot. Or, the requested capacity slot is not available and the control center suggests an alternate slot. In the latter case, the altered capacity slot needs to be checked against the own production plan. If the alternate is acceptable, then it can be confirmed and the capacity plan can be saved internally. On the contrary, if the alternate does not fit the internal resource and production planning, a new request has to be placed or the company withdraws its request. However, in a case of a final withdrawal, the fact that that the production has still to be cancelled or carried out in a later period needs to be taken into account.

[114] For this module, no other reference process models from literature could deliver valuable input. Therefore, the process descriptions of this part are solely based on the theoretical finding of the order fulfillment process and the transformation. In particular this EPC bases on the train path order procedure which has been introduced in chapter 4.2.

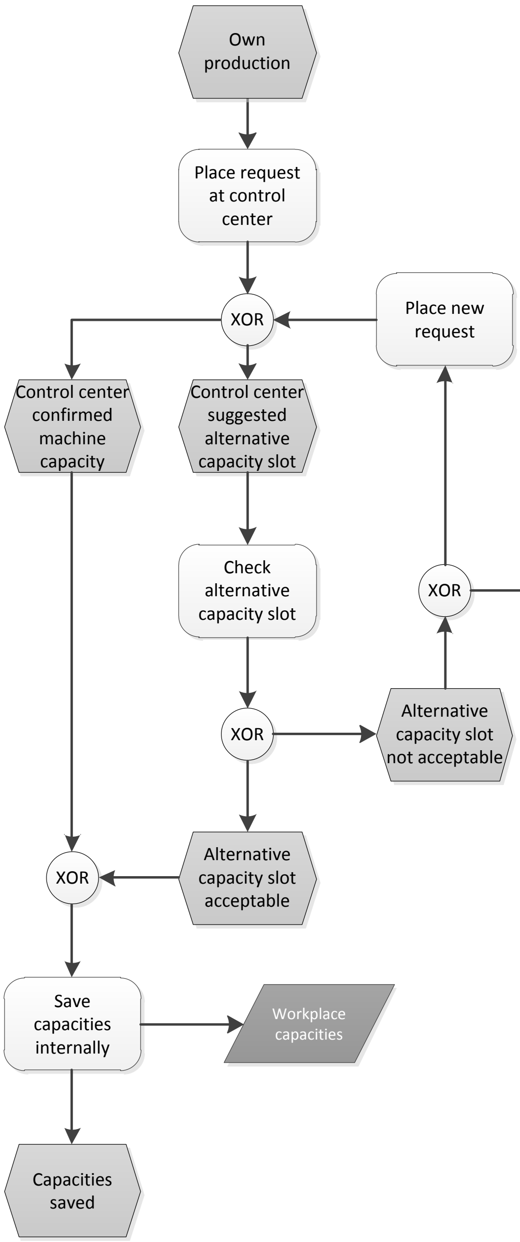

Figure 19: EPC for the Capacity Ordering at the Control Center

5.4.6 Resource Deployment Planning for ATO and MTS Production (VI)

From this point on, (module VI) both, the ATO and the MTS production are covered within the same module in order to achieve synergies between the two different product lines, and to reduce complexity and redundancy. The resource deployment planning module is crucial as it covers the actual resource allocation in terms of distinct resource, i.e. unique tools that are assigned to particular orders. This process (Figure 20)[115] is the sequel to module IV (material requirement planning for ATO production) and module II (order acceptance for MTS production). Also, here both views and the infrastructure capacity will be applied, i.e. the workplace view and assembly view.

To start with, the ATO and MTS orders have to be transformed from the period-based view into the continuous view, which means that the strict distinction between separated periods is replace by a continuous schedule with concrete start and end production dates. Additionally, there are two further possible inputs for this process. So far, only concrete master agreement and early single orders have been taken into account. But now, as the actual starting date of the production comes closer on the one hand, last rush orders might come in. And the customers with flexible master agreements also have to finalize their requests in order to allow a detailed resource allocation.

Eventually, these four different inputs are combined in a simplified production schedule. It represents the ideal production, while ignoring any capacity restrictions. But as it is likely that this simplified scheduling causes inconsistencies, the procedure continues with a check for capacity conflicts. In case capacity conflicts are revealed, the sub-module for capacity adjustments (Capacity Adjustments I)[116] takes over. In any other case, the assigned tools can be reserved right away.

The capacity adjustment can either be carried out by an algorithm (if available) or interactively (i.e. manually). In order to manually achieve a consistent resource allocation, in general there are three possible measures. First, it might help to use another tool instead of the initially scheduled one. Second, what effect a slight change of the start time of the production has (given that the reserved workplace capacity remains still valid) can be evaluated. And third, the sequence of the order processing could be changed. However, as it has been outlined previously, this production system works with strict end dates and end products that are not superposable, which is why sequence and time shifts underlie tight restrictions.

[115] For this module two out of the three potential sources have been taken into consideration. In particular Mertens (2009), pp. 140–148 and Scheer (1997), pp. 210–274

[116] There is also a second module (II) for the later capacity adjustments in the detailed scheduling process (5.4.7).

After applying one or more measures to adjust the capacity utilization of resources, the conflicts can either remain or be solved. If they are solved, the planned tools have to be reserved. If they remain unsolved, there is still the possibility to extend the tool capacity by renting active and passive tools. If this measure eventually helps with the capacity conflicts, the procedure also leads to the reservation of tools. But if this last resort does not help with the capacity conflicts, the order needs to the canceled and the client needs to be informed. However, if the order acceptance and gross planning have been conducted in an effective way, this case should be an exception.

After the capacity has been planned and reserved, the process continues with preparation for the secondary demand planning (switch to the assembly view). This time the secondary demand has to be derived for rush and concretized orders analogue to the material requirement planning (5.4.4). Based on the item list, all orders that still do not have assigned workplace capacity have to be composed down to their assembly parts. As soon as this secondary demand has been derived, the workplace capacity can be ordered by means of the capacity view. From this point on, until the production schedule has been updated, the process matches exactly the description that has already been stated for module IV (s. 5.4.4, p. 58).

As the updated production schedule is the last event of this module, the process continues in the subsequent module. There, for both ATO and MTS products, an even more detailed production schedule is set up.

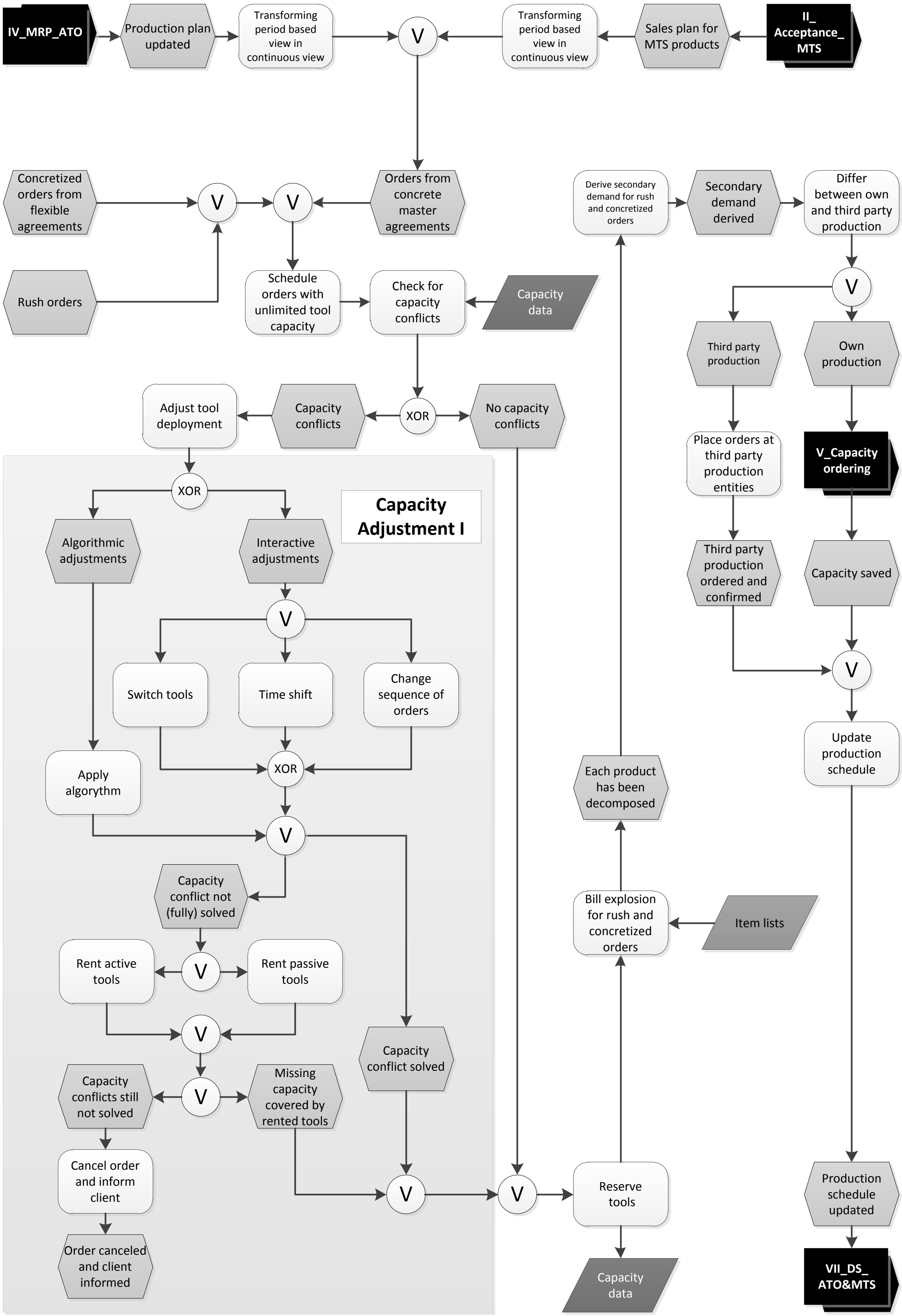

Figure 20: EPC for the Resource Deployment Planning in the ATO and MTS Production

5.4.7 Detailed Scheduling for ATO and MTS Production (VII)

After the resource deployment planning (5.4.6) has been completed, the production schedule needs to be refined by means of this detailed scheduling module (Figure 21)[117]. Again, both business cases, ATO and MTS production, are covered here.

First, the focus needs to be shifted to MTS products only. As it was explained earlier, the special characteristic of this production system is the advantage that the on-stock products are only virtually on stock and, hence, still need to be produced. Therefore, even though resources have been committed to their production from the beginning, the production can still be cancelled in the event not enough products could be sold to the customer. Therefore, the first step asks to cancel those MTS orders that belong to a lot that does not utilize the resource efficiently because too much un-utilized capacity is left over. Once this has been done, the production schedule has to be updated again and, subsequently, all orders should be sorted according to their priority[118].

The prioritized orders are required to run through the tool availability check. Its purpose is to check whether all required tools are already available at the workplace where they are needed to start or continue the production. If the availability check is entirely positive, the process directly continues with the second capacity adjustments. On the contrary, if tools are still missing at the workplace, a process consisting of up to three major steps is initiated. First, whether the missing tools can still arrive early enough to initiate the production process on time has to be evaluated. In case this first step ended with a negative result, it has to be asked if the tools can still be made available if a certain delay is taken into account and accepted. If this request has to be negated, the last option is the shift of tools according to the priority list. The idea is to cancel orders with a lower priority and to use the free tool capacity to carry out orders with a higher priority that are currently suffering from unavailable tools. If this is an option, or if one of the other previous checks could be answered positively, the workflow also leads back to the second capacity adjustment module. It also has to be kept in mind that the production schedule needs to be updated in case tools have been shifted and orders were canceled. Otherwise, the only option is to cancel those orders that cannot be carried out due to missing tools.

After the tool availability check, the refinement of the production schedule takes place. It might be that some alterations that have been applied during the availability check or other unforeseen events cause an imbalance of the resource allocation again. In this case, when the schedule exceeds the capacity limits, once more the three different measures

[117] For this module two out of the three potential sources have been taken into consideration. In particular Mertens (2009), pp. 147f. and Keller, Teufel (1999), pp. 632–634

[118] At this point it is up to the reference process model user to define criteria (customer importance, revenue) he wants to apply in the prioritization.

(switching tools, time shift or sequence change) could be applied. In comparison to the first capacity adjustment, the application of an algorithm seems unlikely as the production is immediately prior to execution and, in most cases, this second capacity adjustment will only have to handle very detailed issues.

If now the last capacity conflicts could be solved, or if there have not been any from the beginning on, production schedule will be updated (if necessary) and the process goes over to the next process module, which describes the production initiation (5.4.8). However, if not all capacity conflicts can be solved, it needs to be taken into account to cancel orders that are affected by the shortage of capacity. Due to the short time period left until the production execution starts, renting tools or re-allocation tools from orders with lower priority is not an option anymore at this point.

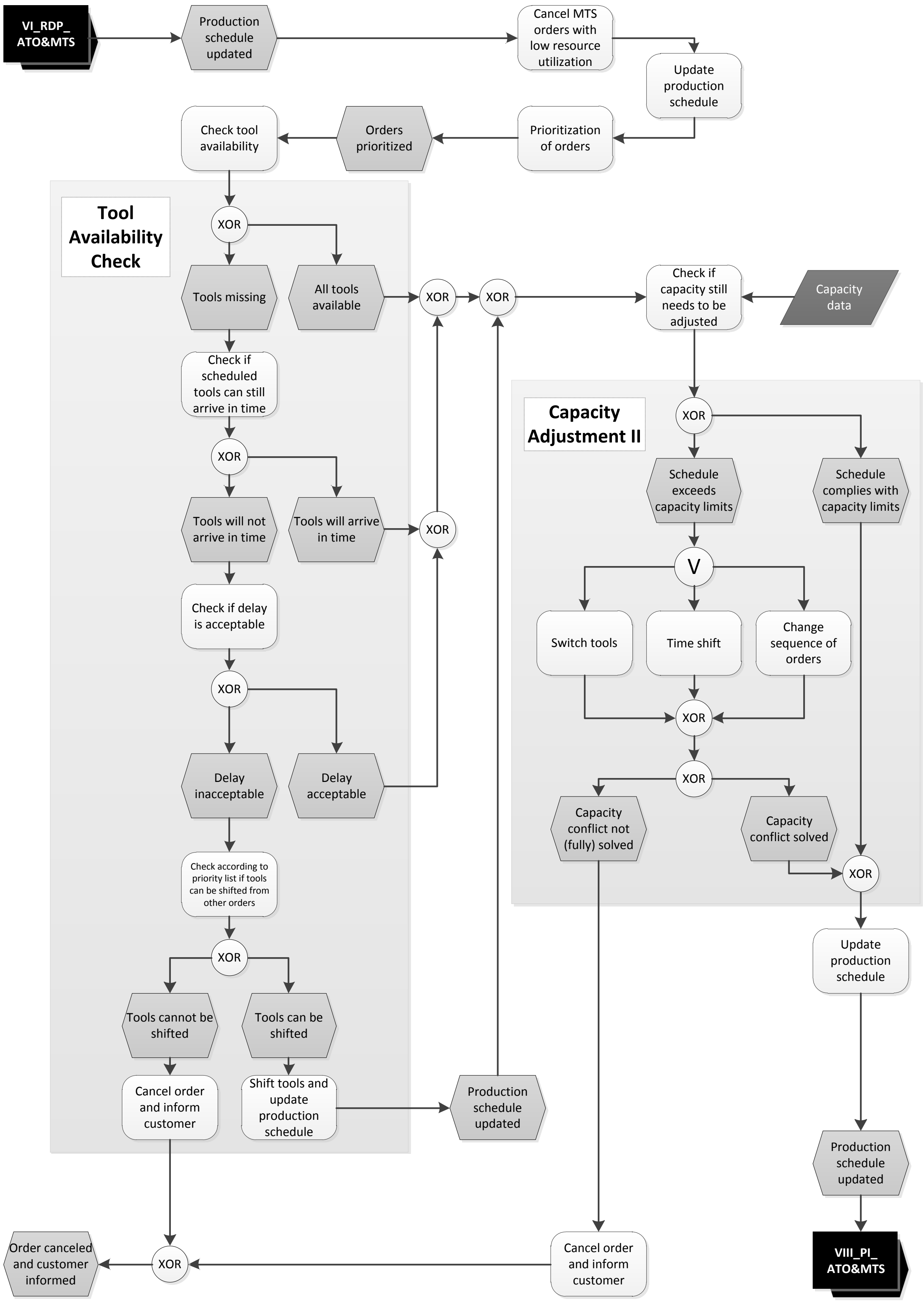

Figure 21: EPC for the Detailed Scheduling in the ATO and MTS Production

5.4.8 Production Initiation for ATO and MTS Production (VIII)

Once the production schedule has been refined and updated for the last time, the production is almost ready to be initiated. However, there are three more final checks that make up the production initiation process (Figure 22)[119]. Also, here both business cases, ATO and MTS production, are covered in the same module.

The first check is the final workplace availability check. It has to be ensured that all workplace capacities that have been booked earlier are still secured. If this is the case, the process flow points to the second check, i.e. the final tool availability check. But if there is workplace capacity missing, the production of the affected product needs either to be cancelled (and then the client needs to be informed, too), or it could run on a dispatching basis. The latter case means that the production starts anyway, well knowing that there are no explicitly booked workplace capacities, with the aim to find free slots in cooperation with the control center while the production is already running.

The final tool availability check is different from the previous tool availability checks, as it does not allow any freedom of action. Either all tools are on-site or the production needs to be cancelled due to the fact that the production is about to start immediately and no corrective measure could take effect.

Once it has been confirmed that all tools are on-site, it has to be ensured that their operational functionality is in-line with the security demands. If this check leads to a negative result, meaning that not all tools fulfill the security standards and are functioning well, the affected order needs to be cancelled and the client needs to be informed. But as this is a rather exceptional case, it is more likely that all tools pass the security check. Subsequently, all relevant information that is required on site to initiate the production will be collected and the order will be released. Even though the following module (production monitoring) is still subsumed under planning, it already represents the execution process (5.4.9).

[119] For this module all three potential sources have been taken into consideration. In particular Keller, Teufel (1999), pp. 630–635 , Mertens (2009), pp. 148–150 and Scheer (1997), pp. 284–288.

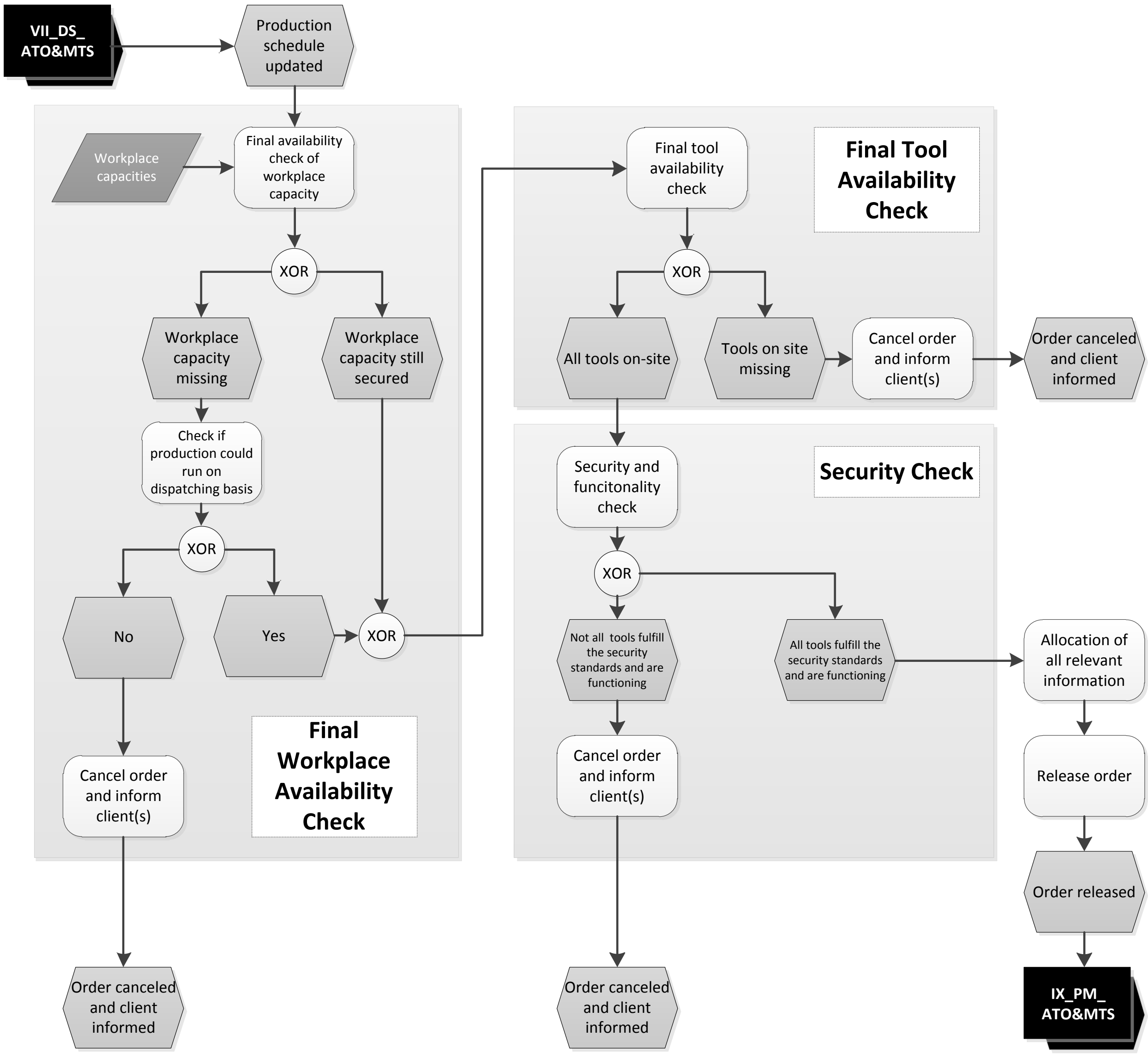

Figure 22: EPC for the Production Initiation in the ATO and MTS Production

5.4.9 Production Monitoring for ATO and MTS Production (IX)

The last module of this reference process model (Figure 23)[120] takes over as soon as the production is initiated by the released order. Again, both business cases, ATO and MTS production, are covered within one module. The purpose of this module is to specify how to react in case the actual production deviates from the initial production schedule. This is also what can be referred to as a *control circuit logic*.[121] Therefore, this module contains a loop that the process runs through as long as the production is not terminated.

As soon as the production starts, all deployed tools should be booked as *in use*. This is important in order to maintain a clear overview of which tools are currently available, for example, to function as a substitute for other orders with a lack of tools. Also, right from the beginning the production monitoring takes place. In fact, this is a continuous function that is applied as long as the production is in progress. As long as no abnormalities occur, for example, deviations from the production schedule in terms of resource deployment and production times, no certain measure needs to be taken and the production continues as planned.

If the production monitoring function detects abnormalities, the left-hand side of the EPC is activated. Three major events might occur: the breakdown of an active tool during the production, the breakdown of a passive tool during the production, or delays in operations. In the first case, the active tool needs to be substituted as soon as possible. For that purpose, the capacity data can be used to check which tools are currently available to be deployed instead. In the second case, the passive tool does not need to be replaced but removed from the production process. In most cases this will be easy, as the passive tool represents an independent carrier medium that is not necessarily required in order to continue the production with the remaining passive tools.

Once the breakdown has been solved, the process continues to evaluate whether the delays in production violate the workplace capacity planning, respectively whether the breakdown led to serious delays at all. If, after all, the workplace capacity slots are still valid, then there is no need for further actions and the production continues according to its initial production schedule. However, if there are expired workplace capacity slots, the production needs to continue in the dispatching mode (cp. 5.8.4). Also, if workplace capacity is expired and the production continues in the dispatching mode, the future resource planning needs to be adjusted, as tools probably will not become available in time to be deployed in their following job. It is important to inform the client about the expected delay.

[120] For this module all three potential sources have been taken into consideration. In particular Keller, Teufel (1999), pp. 636-644 and 650-658 , Mertens (2009), pp. 169–172 and Scheer (1997), pp. 337–342.
[121] Cp. Scheer (1997), p. 283

Independent from whether the production continues according the initial plan or the dispatching mode, the production monitoring (see the back loop on the right hand side in Figure 23) also is ongoing until the production is completed. Subsequently, as a final step, the tools that have been in use until then have to be booked as *available* again in order to ensure that they can be deployed in further jobs.

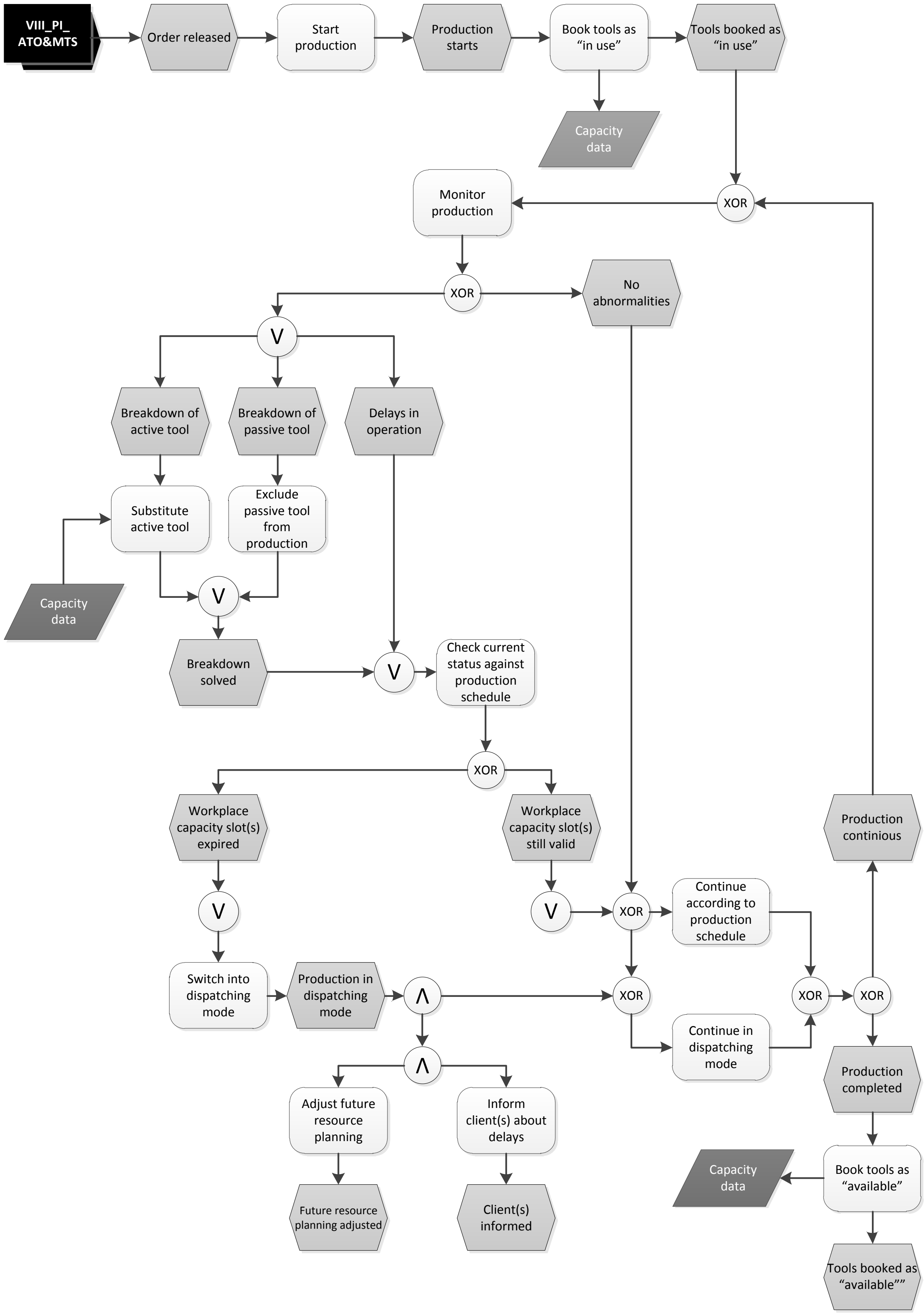

Figure 23: EPC for the Production Monitoring in the ATO and MTS Production

5.5 Software Implementation

In order to apply the introduced reference process model efficiently, it requires an IT based advanced planning and scheduling (APS) system. However, as an in-depth analysis of available software and presentation of an implementation guideline would go beyond the scope of this work, this part only summarizes requirements of the reference process model towards a production IT. The following requirements can be used as a basis for a first market analysis.

Usually, the APS system providers (e.g. SAP) have divided their IT solution into different modules. Therefore, in order to cover the functionality of the present reference model, the focus has to be on the so-called enterprise resources planning (ERP) modules. Here, in particular, the most important functionality that needs to be covered is the **allocation planning of tools**. It has been explained above that most of the tools come along with high capital commitment costs, which underlines the importance of an efficient allocation planning. Additionally, the network character of the production leads to a high complexity of the tool allocation, which is why the software solution should offer a **built in algorithm** for the deployment planning (cp. also 5.4.6). In this context, whether the software includes suitable **operation research (OR) methods** for the resource planning and allocation has to be examined. And even though they have not been part of the present model, **further resources** should be covered as well, such as human resources or maintenance capacity.

Moreover, the software is not only supposed to offer these planning functionalities but also to **process status information in real time**. For the allocation planning, it is crucial to have real-time information about the tool status. Consequently, there also has to be the possibility to present this real-time information to the system user. This underlines the importance of a **graphical user interface** in order to illustrate information in the best possible way (e.g. network maps, gantt charts).

Besides the functionality, the target group or industry also is important. Here, an IT solution that is **not restricted to any particular industry** and which offers various possibilities for customization and adjustments is recommended. This is important, as the reference process model has been developed based on a transformation. In order to allow railway companies to apply this model, it has to be re-transformed into the logistics terminology, which also means that the application software has to be capable to function **equally efficient under the logistics terminology**.

With regard to the software provider itself, the market leaders (such as Oracle or SAP) should be explored first. The rail-bound logistics business is highly internationalized and this trend will be amplified even more in the future. Therefore, the software provider also should be able to **offer international and multilingual support**. For example, this requirement can be underlined by the international expansion strategy of DBSR, which already operates as an international railway provider with many entities abroad.[122]

So far, the focus has been only on ERP modules, but it is also important to take the **expandability** of the IT solution into account. With the reference process model and a suitable ERP module, only a small fraction of the entire business functionalities of the rail-bound logistics can be covered. Therefore, in the long run, it should be possible to extend the IT solution with **various other modules**, such as customer relationship management (CRM) or data warehouse functionalities for controlling and reporting needs. The **need for a CRM module** could already be seen in the process description above, as nearly all workflows contained numerous interfaces with the customer where orders could be placed, canceled or updated.

[122] Cp. DB Schenker Rail Deutschland AG

6 DB Schenker Rail Romania Case Study

This chapter marks the last step in the meta development model. At this point, the developed reference process and, in this vein, the transformation will be validated by means of a case study. The case study is based on the Romanian railway operator DBSR Romania.

At the beginning, an introduction to DBSR Romania will be given (6.1). This part contains a general company presentation and explains the role of DBSR Romania in the DB Mobility and Logistics AG. In a second step (6.2), particular information on the peculiarities in operations are given. The purpose is to prepare the individual application of the reference process model. Third, the current order fulfillment process will be illustrated and described in order to build up a reference against which the developed model has to be compared before it can be applied (6.3). Finally, the fourth part (6.4) contains the actual application of the reference process model. This application is carried out in two main steps that eventually lead to a strategic fit between model and company. First, the model itself is customized and prepared for the application and, second, necessary adjustments of the company's organizational structure and IT landscape are outlined.

6.1 Introduction to DB Schenker Rail Romania

DBSR Romania, founded in 2000, is a foreign subsidiary of the international rail freight operator DBSR. Besides DBSR Romania, various other national and international entities belong to the DBSR Group, which has structured its business according to three different European Regions: West, Central and East.[123] Further, DBSR is one of nine different business segments of the Deutsche Bahn AG (DB AG) holding and belongs to the "Schenker" brand, which bundles all freight logistics activities of the holding. On the contrary to DBSR, DB Schenker Logistics covers all activities in the field of national and international road-, sea-, and air-freight transportation.[124] Therefore, the DB AG holding comprises all four different modes of transport on a global level and, hence, is able to offer complex supply chain solution from door to door. Eventually, every business segment benefits from this extensive logistics network. Table 14 illustrates the dimensions of the three different holding levels DB AG, DBSR Group and DBSR Romania in terms of turnover and earnings before interest and taxes (EBIT).

[123] Cp. DB Schenker Rail Deutschland AG (2011)
[124] Cp. DB Schenker AG (2011)

Table 14: Key Financial Figures of DB AG, DBSR Group and DBSR Romania[125]

Key Figure (in mil.)	2009[126]	2010
Turnover		
DB AG	28,406	33,152
DBSR Group	4055	4,584
DBSR RO	9.023	17.599
EBIT		
DB AG	1,013	1,130
DBSR Group	-189	12
DBSR RO	0.582	0.339

DBSR Romania itself was founded as a shunting operator, but since 2004 it also has been expanding its businesses in the field of traction. Currently DBSR Romania counts about 170 employees, 35 shunting and traction locomotives and about 420 wagons. During the summer season in 2011, the company performed about 1,000 distinct train runs and approximately 70,000 train kilometers per month. It is one of the fastest growing DBSR entities in Europe. Since the end of 2008, a strong focus was set on the extension of the traction services in Romania and the company's traction fleet. Table 14 exemplifies this strategy as the turnover nearly doubled in one year while the EBIT even decreased due to heavy investments. Another thing that plays a key role in this light is the separation of the branch in Bulgaria (DBSR Bulagria), which has been running its business independently from DBSR Romania since February 2010.

Regarding the competitive situation, in 2010, DBSR Romania had a market share by turnover of 3.7%, which is the fifth highest in the Romanian market. The biggest two shares belong to the national operator CFR (Căile Ferate Române) Marfa with 51.27% and the largest private operator GFR (Grup Feroviar Român) with 26.77%. The remaining 18% is split between the private operators STI (Servtrans Invest), UT (Unifertrans), TFG (Transferoviar Grup) and CTV (Cargo Trans Vagon). All shares in terms of percentage and absolute figures can be found below in Figure 24.

[125] DBSR RO figures taken from Ministerul Finanţelor Publice (2011). All other figures taken from Deutsche Bahn AG (2010) and Deutsche Bahn AG (2011).
[126] In terms of DBSR RO: Contains also a share of the business performance of the branch DBSR Bulgaria which belonged to DBSR RO until the 1st of February 2010.

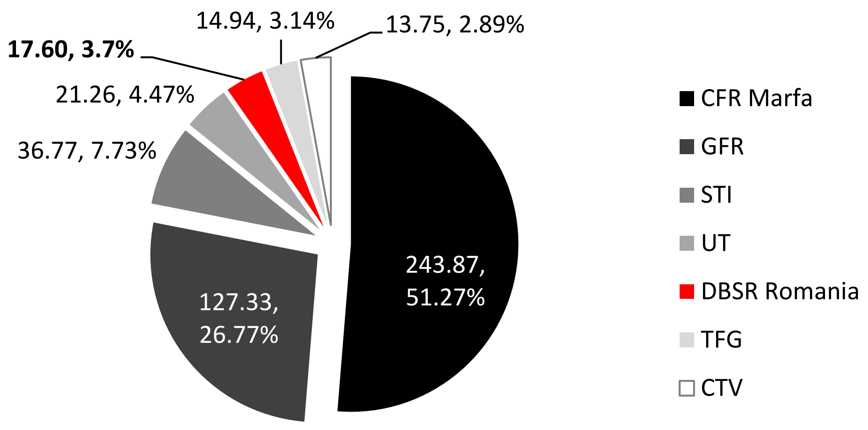

Figure 24: Market Share of Romanian Railway Operators Based on Turnover (in mil.) in 2010[127]

6.2 Peculiarities in Operations of DBSR Romania

This part covers both the peculiarities of the Romanian rail-bound logistics system itself (external circumstances) and peculiarities with regard to the production concept of DBSR Romania (internal circumstances). With regard to the external circumstances, the infrastructure capacity ordering procedure is especially important to mention. Due to the fact that the capacity can be ordered only from approximately ten days in advance on, there is no distinction between regular and short-term paths. Therefore, compared to other countries (e.g. Germany) the path ordering procedure is quite simple, as also no extra fees or fines arise when cancelling or rescheduling paths on very short notice.

Another interesting peculiarity is the topological arrangement of the Romanian railway network. The Carpathian Mountains run right through the middle of Romania, which leads to a high declivity at many points of the railway network and, hence, affects the production concept of the railway companies (e.g. splitting trains into two couples at certain points). Due to these topological constrains, but also due to the low quality of the railway network (e.g. maximum weight restrictions of bridges, low speed limits), many parts of the network cause delays and become bottlenecks. However, as a consequence of these circumstances, the Romanian customers (in general) are also less sensitive about delays in operations and, thus, have lower-quality demands regarding the transportation time.

From the internal perspective, one of the most important subjects is the product portfolio. So far, DBSR Romania does not offer any wagonload, but only trainload transports. Also, practically, DBSR Romania does not offer any master agreements with fixed conditions, but instead the company works a lot with flexible master agreements that only

[127] Combined from various reports from Ministerul Finanţelor Publice (2011).

state certain quantities within a distinct time frame. This also is due to the infrastructure capacity ordering procedure, which only works on very short notice (see above). In this context, the entire resource planning process also has a very short time horizon of 30 days maximum (see 6.3).

The resource utilization, in terms of the deployment of locomotives, is also special at DBSR Romania. First, on many relations the company operates with dedicated resources, which means that the affected locomotives are not integrated in the circulation planning. Eventually, this leads to higher resource availability and less complex planning problems at the expense of the resource utilization.

It must be noted that DBSR Romania is not in possession of any holistic production IT that would facilitate the order fulfillment process. Rather, there are various single (and independent) systems and tools in use that will be introduced in the next part.

6.3 Current Order Fulfillment at DBSR Romania

This section provides an overview of the current order fulfillment process and the connected resource planning at DBSR Romania. Figure 25 shows a highly aggregated EPC of the process, containing the following stages: order acceptance, monthly planning, 10 days planning, capacity ordering I, 24 hours planning, capacity ordering II, and production execution. In the following, these seven stages will be presented and for each stage the affected and deployed units (functions and departments)[128], as well as systems and tools, will be assigned and introduced accordingly. As the capacity ordering (I and II) is always closely connected to the previous stage, below it will be presented in the same paragraph.

Figure 25: Aggregated Current Order Fulfillment Process at DBSR Romania

In addition to the EPC above, a more detailed view is provided by Figure 27 at the end of this section. The matrix summarizes at which stage the different units, tools and systems are used.

[128] The term *function* refers to a specific job description (or workplace) and allows to take a more detailed view on a particular *department*. In this context, the production department will be broken down into three different functions (operations manager, planner and dispatcher) while the sales department , which is only partly involved in the process, does not require a more detailed perspective.

Order Acceptance

The Order Acceptance is carried out by the **sales department** in collaboration with the production department (represented by the **operations manager**). The sales department requests price and capacity information from the production department and, based on this, an offer is made to the customer. On an aggregated level, this stage also contains the three main elements of the acceptance module (I) in the reference process model, namely feasibility, reliability and CTP check. However, there is no extensive and standardized workflow in place and also no clear division of responsibilities between the sales and the production department. The current process represents an internal iterative negotiation process without clear procedure guidelines.

Monthly Planning

It is the task of the **operations manager** to collect the demand from the customer side for the upcoming month. At this point, only demand from the flexible master agreements is relevant. This demand is documented in production system **TRIP** (train reporting in production) and is modified and refined over time until the production is terminated.

Concrete departure times are not stated at this point. Also, later, the actual point of departure may differ plus or minus one day. With the set up list of the aggregated demand, the **planner** continues the process. The next step is to conduct the monthly planning according to the rules by the infrastructure provider (in the following referred to as CFR Infrastructure). On the 28th of each month it is the duty of every Romanian railway operator to state what quantities he expects for the upcoming month. At this point, no concrete days or even paths are reserved. The infrastructure provider only wants to know how many times the operator plans to serve a certain relation in the network with loaded or empty trains. Light engine runs are not considered at this early stage, either. This monthly planning is conducted by means of the **CFR website**. The **planner** states every month the aggregated demand for the upcoming period by entering it in the online platform.

10 Days Planning and Capacity Ordering I

Simultaneously with the monthly planning, the first 10 days of the month are planned in a concrete way. And, in addition to planning on the 28th of the previous month, the same module is carried out on the 8th of the actual month, as well as on the 18th. Figure 26 exemplifies the overlapping of monthly and decade planning.

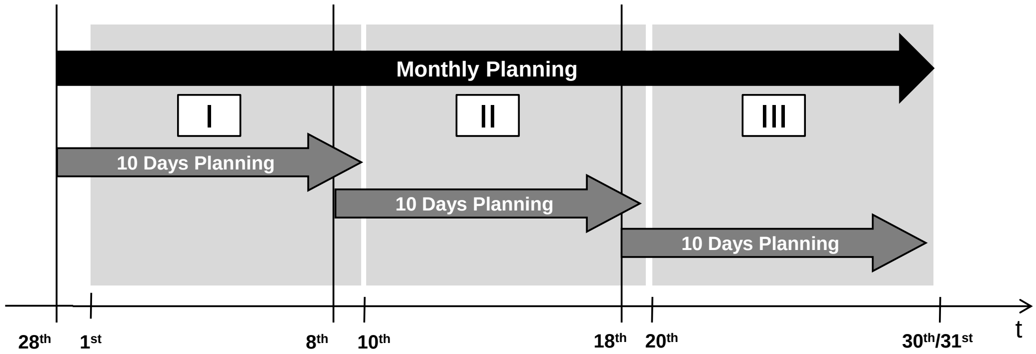

Figure 26: Overlapping of Monthly and 10 Days Planning

In comparison to the monthly planning in which only traffic days for certain relations have been specified (quantity planning), in the 10-days planning, concrete train paths are ordered for the first time, including departure and arrival time and date.

As between the monthly planning and the second (II) and third (III) 10-days planning lie several days two main alterations might occur. In comparison to the monthly planning, on the one hand, customers might adjust their initial orders. On the other hand, additional (short term) requests by the customer, which are referring to the upcoming 10 days, might come in. Therefore, the 10 days planning can be based on up to three inputs: the initially set up monthly plan, adjustments by the customer, and additional customer requests.

However, every 10-days planning module has the same structure, independent from the type of input. The main action is to complete an MS Word-based **order form** in which all planned loaded and empty trains for the next ten days are listed. Here, the **planner** enters the points of origin and destination, the gross tonnage, the lengths and the desired date and time of departures. Then, this form is printed out and sent via fax to CFR Infrastructure. After the form has been submitted (and CFR has been processed the requests for infrastructure capacity), the **planner** can check the order status online. For that purpose CFR Infrastructure provides a section on its **website** where all requested train paths are listed. The planner can see which paths have been accepted and which paths have been denied and substituted by an alternative path suggestion. In case all or some paths have been denied, he enters an online negotiation procedure with CFR Infrastructure as long as he cannot accept the alternative path suggestions. Eventually, if all paths have been accepted by both sides, the 10-days planning module is complete and the planner updates the planned information in **TRIP**.

24 Hours Planning and Capacity Ordering II

Between the 10-days planning and daily planning can be up to 10 days. The longer the time period between these two planning modules, the more likely it is that additional customer requests might come in on a very short notice. Also, again, the customer has the possibility to adjust earlier requests. These two additional events and the initial 10 days plan represent the input for the daily planning. At this point, the concrete resource allocation takes place, for example, the assignment of particular locomotives and wagons to the scheduled orders. An important input document for the locomotive circulation planning is the **locomotive plan**[129], i.e. another MS Word document that contains the position and future job descriptions of each locomotive. This document is updated daily by the **dispatchers** and is used to decide which locomotive should operate in which train. Additionally, the dispatchers have the option to use the **GPS** signal of the locomotives in order to find out about the current position in the railway network. The GPS signal is visualized online by means of a map of Romania (based on Google Maps).

After the locomotives and human resources are assigned, the daily plan can be submitted via the **CFR website** again. At this point, paths need to be ordered for light engine runs and short-term requests that have not been included in 10-days planning. Additionally, already ordered paths might be adjusted according to altered customer requests. This module is carried out by the **planner** in cooperation with the **dispatcher**, whereas the planner only has a supporting function (grey shaded areas). Again, all updates of planned information are entered in TRIP.

When the daily plan has been submitted online to CFR Infrastructure (the application of the MS Word order form is not necessary anymore), another online negation procedure takes place. However, it is analogue to the one embedded in the 10 days planning module (see above) with the only difference that now light engine runs also are scheduled and the production happens immediately prior to execution.

Production Execution

As soon as the production starts, the **dispatcher** begins constantly comparing the current status with the planned information in **TRIP**. Information about the current status can be retrieved via multiple channels, such as via phone connection to the locomotive driver, **GPS** signal or the updated train status on the **CFR website**. If abnormalities occur, the dispatcher has the responsibility of ensuring that the production continues as smoothly as possible. However, here concrete procedures and guidelines for troubleshoot actions also are missing.

At the end of each production procedure, the **dispatcher** finalizes the information in **TRIP** in order to ensure that the system contains the real parameters for each train run (e.g. trailing tons, travelled distance, etc.). He also updates the MS Word **locomotive plan** in order to supply the next shift with updated information for the upcoming locomotive circulation planning.

[129] Internally referred to as “Predarea Serviciului”.

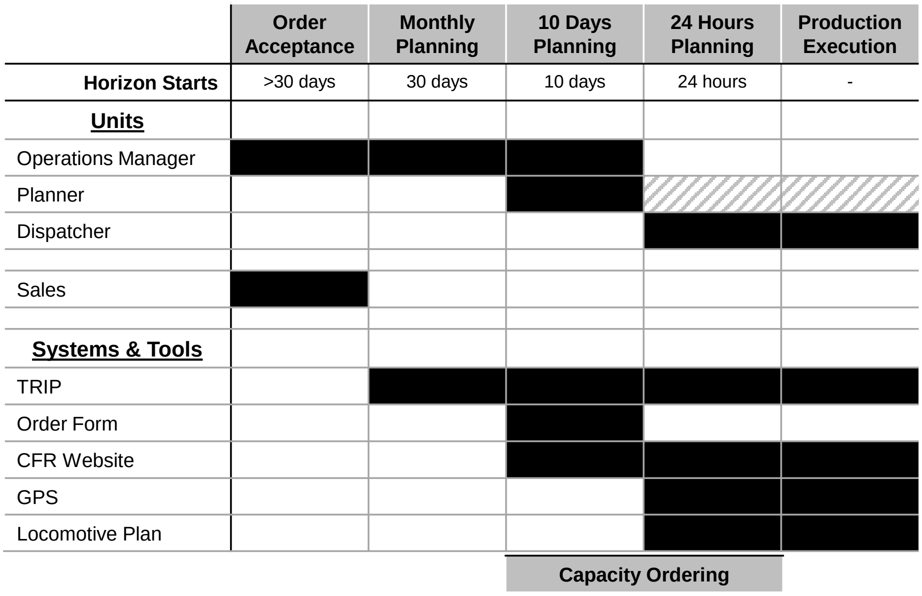

Figure 27: Units, Systems and Tools in the Current Order Fulfillment Process

6.4 Application of the Reference Process Model

The peculiarities in the current operative production planning process have been introduced above. Based on these insights, it can be decided how to implement the developed reference process model at DBSR Romania. In this context, two questions, especially, need to be answered: which parts of the model can be applied without adaption and which parts require customization; and in which areas does the company's organization and system and tool landscape need to be adapted. This two-sided approach will eventually lead to a strategic fit between company and reference process model.

However, when it comes to adaptions on the company side, given the limited scope of this work, no drastic modifications will be outlined here. Also, in general, the application of the reference process model should not require the company to change its organization entirely.

The following three parts will lead to the strategic fit between model and company. First, on a very aggregated level (seen from the model's first level) both, the current planning process and reference process will be aligned in order to see which modules cover which stages of the current process (6.4.1). Next, a closer look at each single module is taken in order to point out necessary adjustments on a more detailed level (6.4.2). Eventually, the necessary company adjustments also will be outlined (6.4.3).

Also, from now on the reference process model will not be applied with its native terminology, but based on a rail-bound logistics language. This re-transformation is crucial as it is a basic requirement towards the usability for the end users.

6.4.1 First Level Alignment

The first approach towards a customized reference process model is to narrow the model down to the required parts and to cross out elements which that are not relevant to the concrete case. On the first level, it has be decided from a more aggregated point of view which modules to apply and which to neglect. On the second level, single functions or group of functions will be taken into account.

Due to the fact that DBSR Romania does not offer any wagonload but only trainload transports, in a first step the whole lower part of the first level matrix can be crossed out. This affects the entire module II (Order Acceptance for MTS Production) as well as modules VI to IX in the way that they are only supposed to cover ATO, i.e. trainload cases. Additionally, master agreements with fixed conditions are not part of the product portfolio of DBSR Romania, which is why this fragment (case B) also can be excluded. This will have some implications for the adjustments at level two as well.

Comparing the current and the reference model process reveals many similarities. The idea is to find analogies for the current planning stages in order to easily define planning horizons for the modules of the new model, and also to determine which units, systems and tools have to be applied in which module. Figure 28 shows which stages will be replaced by which modules of the new reference process model and also which planning horizon refers to which module.

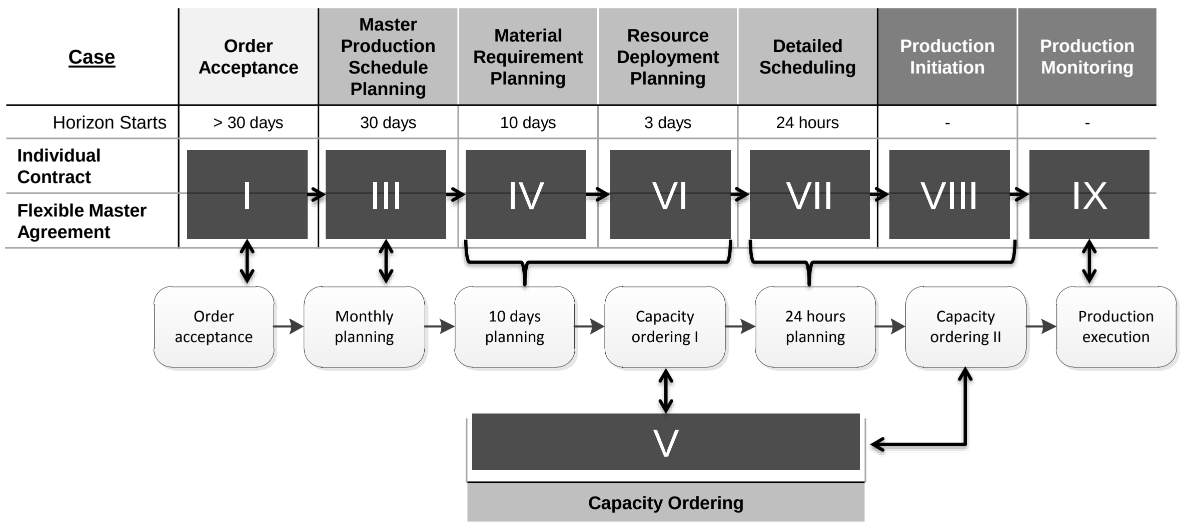

Figure 28: Alignment of Current and Reference Process Model Processes

The first two modules are relatively easy to align with the company's current way of handling the order fulfillment process. The order acceptance module (I) can practically substitute the former order acceptance process and starts at least 30 days in advance from the planned production date, respectively prior to the master production schedule planning module (II). The later one then replaces the DBSR RO monthly planning approximately 30 days in advance. Subsequently, the former 10 days planning at DBSR RO will be broken down into two distinct modules: material requirement planning[130] (IV) and resource deployment planning (VI). Thereby, it also is achieved that the deployment planning of locomotives and wagons takes place already earlier than 24 hours in advance. However, also within the detailed scheduling module (VII), it still has to remain an option to assign locomotive to orders, similar to the former 24 hours planning. This, in turn, however, means that the capacity ordering module (V) has to be extended, meaning that it now runs in parallel with three modules, namely IV, VI and VII. For the second level, this means that for module VII an interface to module V still has to be created, as it is not a standard built-in in the initial reference process model and, hence, has to be handled in the customizing phase (see below). Additional, it is important to mention that the production initiation (module VIII) will be aligned within the last 24 hours prior to departure. The last stage (production execution) can be covered by the correspondent module number IX in the reference process module.

6.4.2 Second Level Alignment

After the model has been adjusted on the aggregated first level, what implications these changes had on the second level must be evaluated. Also, at this point single functions or parts of the process flow can be customized (removed or slightly re-arranged) on a more detailed level.

Order Acceptance (I)

There are no adjustments required at this level. The module can be applied as introduced above.

Master Production Schedule Planning (III)

There are no adjustments required at this level. The module can be applied as introduced above.

[130] In fact the name *material* requirement planning is not suitable anymore. However, in order to maintain the connection with the previous chapter, the re-transformation of the terminology will apply only to the second level in this work. In this case though, the term *capacity* would cover the term *material*.

Material Requirement Planning (IV)

There are no adjustments required at this level. The module can be applied as introduced above.

Capacity Ordering (V)

There are no adjustments required at this level. The module can be applied as introduced above.

Resource Deployment Planning (VI)

In this module, a few parts can be removed. First, an interface with the order acceptance module for wagonload transports is not required anymore. Second, within the sub-module *capacity adjustment I*, the adjustment by algorithm can be removed. For that, the IT infrastructure at DBSR Romania still is not developed enough. Additionally, it first has to be examined whether software that could handle this exact planning problem already exists. Figure 29 illustrates these adjustments.

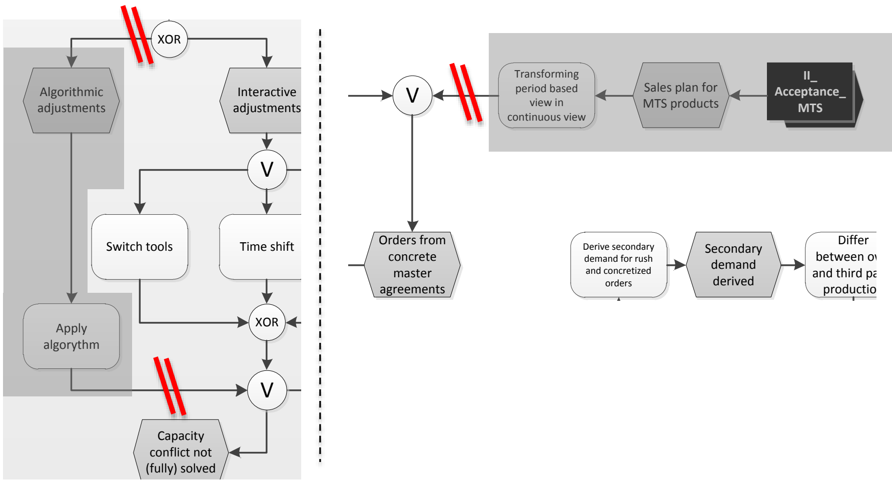

Figure 29: Negligible Parts in Module VI

Detailed Scheduling (VII)

In this module, two functions can be neglected, i.e. the cancellation of MTS orders and, consequently, the production schedule update (Figure 30). Additionally, an interface to the capacity ordering module (V) has to be added because the initial model was only designed for a capacity ordering in parallel to modules IV and VI. The amendment of this additional interface will be located at the end of the process flow in this module – after the locomotive and wagon availability check and the second capacity adjustments have been carried out (Figure 31). To be precise, now the module V itself (see above) also would require an update, as the event that occurs directly prior to the interface is named *capacity update* *needed*. Strictly speaking, this event also should appear at the beginning of module V (not shown).

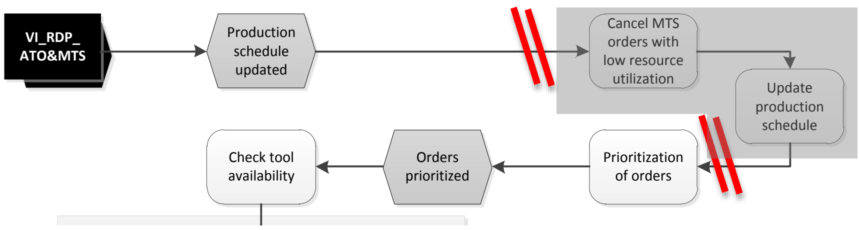

Figure 30: Negligible Parts in Module VII

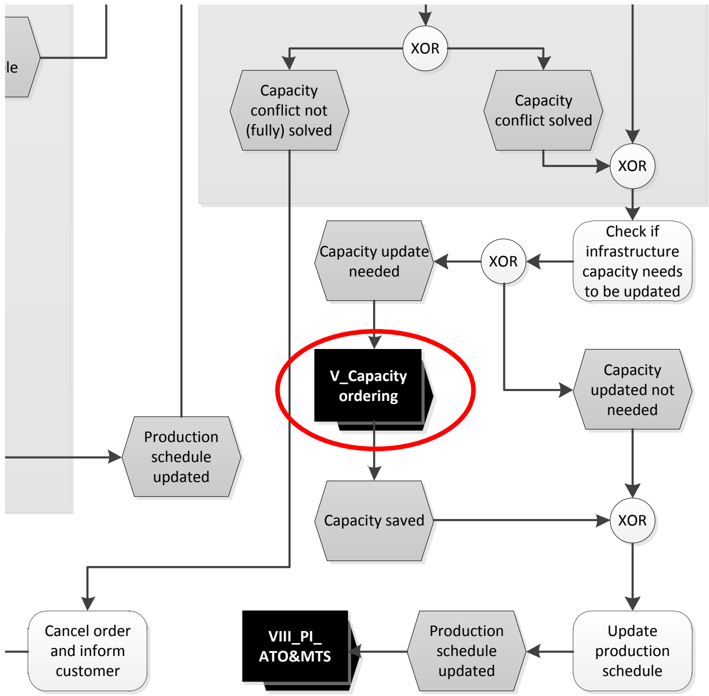

Figure 31: Additional Interface to the Capacity Ordering Module

Production Initiation (VIII)

There are no adjustments required at this level. The module can be applied as introduced above.

Production Monitoring (IX)

There are no adjustments required at this level. The module can be applied as introduced above.

6.4.3 Organizational Structure and IT Landscape Adjustments

A strategic fit between model and company can be achieved only if, at the company's side, adaptions also are carried out. These adaptions can be divided into two parts: on the one hand, the re-distribution of tasks and responsibilities and on the other, the adjustment and harmonization of the IT landscape. This structure also matches the logic of the matrix (Figure 27) introduced in 6.3. Hence, the adjustments proposed in this part also will be illustrated according to the matrix logic (see below). This will allow comparing both matrices against each other in order to quickly review the necessary changes and its implications.

With regard to the units, in general, a stricter and less ambiguous distribution of tasks is required. Additional, each unit introduced above also will have to deal with new responsibilities as the model includes extended planning tasks at many points.

Starting with the order acceptance module (I), a decision has to be made as to whether the operations manager or the sales department is the main responsible unit. The current situation with both units being equally in charge and both having an interface to the customer side is not efficient. Therefore, at least for the long-term master agreements, the sales department should represent the only interface to the customer. Hence, the operations manager is involved in the order acceptance modules (I) only at the request of the sales department related to the feasibility and CTP check. This new distribution of responsibilities is illustrated by the grey shaded area (which represents a support function) in Figure 32.

Concerning the former monthly planning (now the master production schedule planning), no changes will occur as this module (III) is further on assigned to the operations manager. However, the 10 days planning (now the material requirement planning) is no longer in his scope of responsibility. This module (IV), and also the module of the resource deployment planning (VII), will be assigned, now, to the planner only. Again, this re-distribution is about an unambiguous definition of responsibilities but also due to attempt to assign most of the interactions with the infrastructure provider to one single unit.

For the last three modules (VII, VII, IX), the dispatcher will remain in charge. However, the supporting function of the planner is no longer explicitly defined in the implementation plan, as the experience has shown that he was too much involved in the actual dispatching tasks and, so, the actual planning was neglected. Now it is only the task of the dispatcher to carry out the production as close as possible to the resource allocation plan and, also, to make necessary adjustments if needed.

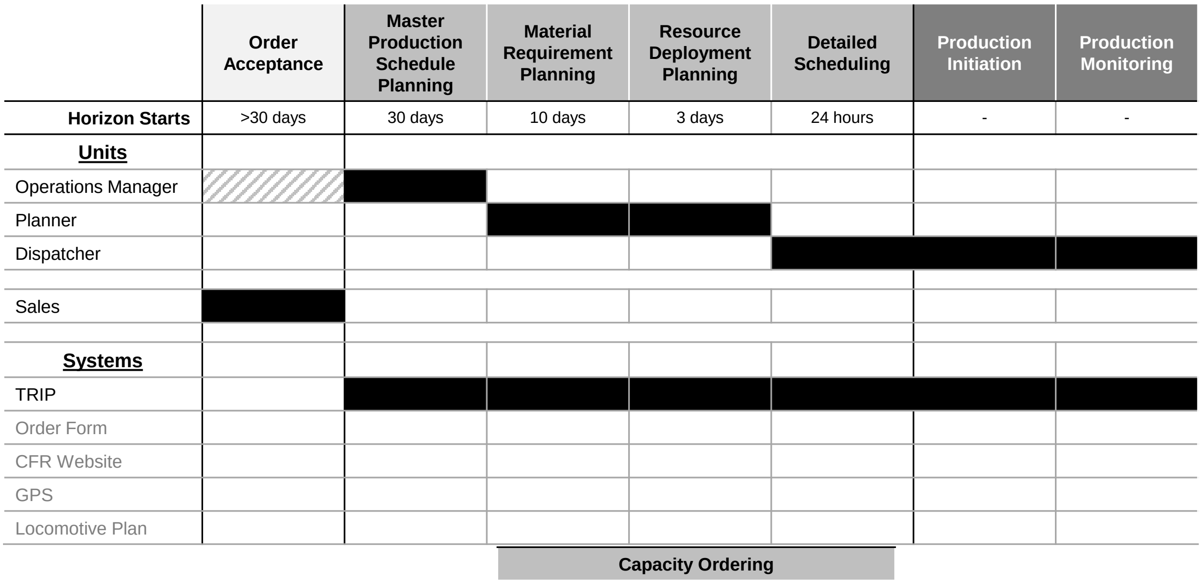

Figure 32: Units, Systems (and Tools) after the Implementation.

With regard to the IT landscape, the overall proposition is to extend TRIP towards a holistic platform that is capable of covering nearly all IT functionalities within the entire order fulfillment process. There are two main reasons for this proposal. First, a closer look at the applied IT reveals that TRIP is the only real system. All other elements listed above are nothing but small tools that represent, so far, standalone solutions. Second, the acquisition of a professional production IT as introduced in 5.5 would probably require investments that would go beyond the budget of a medium-sized company like DBSR Romania. The extension of TRIP in cooperation with a local software developer seems cheaper and sufficient for the foreseeable future. In this vein, it is recommended to embed the following tools in TRIP and to extend the TRIP by the following functionalities:

- Automatized creation of the CFR order form. Based on the entered planning data in TRIP, the required infrastructure paths are summarized in an exportable order form that can be submitted electronically to CFR infrastructure.
- A built-in CFR communication module that substitutes the direct access of the CFR infrastructure website. This would allow for comparisions of the initial plan and possible alternative paths suggested by CFR infrastructure. These deviations in the path ordering also could be visualized graphically (cp. Figure 11 in 4.2).
- A built-in GPS interface. This would help to localize the locomotives within the extensive railway network and help in calculating the set-up times (e.g. light engine running times that occur when a locomotive has to travel to another point in the network in order to start the next job).

- Based on the GPS interface, a more advanced locomotive circulation planning tool. Also, here a graphical user interface should be implemented, which would help in assigning locomotives and wagons to orders. A common tool for that is a gantt chart, which displays all pre-planned orders on the vertical axis while locomotives (displayed as small blocks) can be assigned by drag and drop functionality. Eventually, the size and color of the locomotive blocks indicates the resource usage time and possible conflicts.

7 Critical Acclaim

There are two main perspectives by which this work should be evaluated. On the one hand, there is the question to what extend the initially defined goals have been reached. In particular, this perspective refers to the quality of the transformation and, based on that, also the quality of the developed model. On the other hand, the approach itself needs to be evaluated. This addresses the question of whether throughout the whole course, scientific standards have been applied and whether the approach is consistent.

Starting chronologically, first, the applied meta development model needs to be questioned. Here it can be evaluated positively that the course of this work followed a pre-defined guideline that was taken from various specialist literature sources. Through this, the probability of mistakes could be reduced and a consistent approach could be ensured. However, it has to be mentioned critically that due to the limited scope of this work the initially suggested feedback loop in the meta development model (which aims at iterative improvements) could not be applied.[131]

Another element of this work that needs to be evaluated critically is the applied patterns of the order fulfillment process. Also here, the fact that the transformation criteria have not been chosen arbitrarily but on literature based concepts counts towards the quality of the approach. However, it ought to be asked whether these strictly defined patterns, on the one hand, restricted the transformation too much or, on the other hand, forced the rail-bound logistics systems into a pre-defined shape. In the light of the patterns, it also needs be taken into account that Spengler already mentioned that the classification of a service industry (like the rail freight sector) is more ambiguous and not as simple as that of the physical production.[132]

Concerning the transformation itself and the achieved results, a positive conclusion can be reached. In the end, the transformation did not leave any open questions. Both, an equivalent production system and equivalent orders could be derived. Also, the dictionary for the transformation of railway terms can be regarded as a simple but significant tool. The only weakness in the transformation might be seen in the fact that some transformation criteria could not be applied entirely unambiguously. There are some criteria with multiple selections (e.g. multiple-stage and circular production units) but these ambiguous classifications can occur in the classical production as well.

[131] Towards the feedback loop cp. also Kallenberg (2002), pp. 50f.
[132] Cp. Spengler, Dyckhoff (2010), p. 16

Turning now to the developed model itself, it shall first be assessed with regard to the stated requirements towards reference process models from chapter 2.1. There it was outlined that a model ought to be reusable and adaptable. The adaptability already could be proven through the case study, as certain parts have been crossed out or functions have been added. Also the reusability character can be seen in the model because of its modular structure (which was another requirement) and its neutral approach without any relation to concrete business cases. In this vein, it can be followed that the attribute *universality* applies to the model. On the contrary, the last two characteristics, namely the representation of best practices and a high user acceptance have to be reviewed more critically. Here it ought to be asked, how to identify the best practice, as this model is the first of its kind. From the point of the view of the classical production sector, it can be easily concluded that only the newest theories and specialist literature have been taken into account. But at this point, it is not possible to evaluate whether the model also contains a collection of best practices for the rail-bound logistics. Also, with regard to the user acceptance, at the moment no conclusion can be drawn due to the fact that the model has not been applied in practice and under real conditions.

In addition to the general criteria applied above, further aspects of the model can be evaluated. A comparison between the initial problem and the given scope shows that this work did not offer enough space to develop a full-blown reference process model. Therefore, all critical judgments that are undertaken here should keep the restricted scope in mind. However, this is also to say that this work offers a lot of potential for further extensions of the developed model. Due to the limited scope, various assumptions and simplifications also had to be made prior to the actual modeling process. In this context, for example, capacity restrictions in the vertices were left out, or the entire problem of the human resource planning was not embedded. These are only two examples of subjects that could be included in a subsequent survey, even though it has to be kept in mind that (independent from the available scope) assumptions and simplifications are part of the nature of a model. This is the general criticism towards every model, as it always represents a simplified projection of reality.

The application of the event-driven process chain modeling language is another aspect that counts for the quality of the model. The EPC technique represents one of the most advanced and widely used modeling languages. This also could be seen in the sources (cp. 2.3) that have been used for the development. However, the EPC technique also has limits, especially with regard to the illustration of iterative and dynamic processes that go beyond a linear flow. Therefore, it might be of advantage to model single modules with another or an additional technique. One example would be the production monitoring (module IX) that consists of numerous logical requests that make up a feedback loop. Also, for the software implementation, a conversion of the model into an additional modeling language that is closer to the IT level is recommended (e.g. the ERM language).

Eventually, the model also can be evaluated based on the case study. The major point of criticism is that the case study did not include a testing of the model under real conditions, but only a theoretical alignment with the organizational structure and IT landscape. However, this is again due to the limited scope that was mentioned above. Taking that into account, a positive conclusion can be drawn. The case study could show that, at least in theory, the implementation works and, hence, the transformation could be validated. Certainly, in a further elaboration on this topic, a practical implementation of the model should follow, too. In this vein, the user acceptance (see above) also could be evaluated and the quality of the model validated to an even greater extend. Additionally, for DBSR Romania the case study might contain valuable input for improvements of their planning and steering process; even if the entire model should not be implemented in the near future.

To conclude, the overall picture can be put into a nutshell: The transformation was successful and the model could be theoretically applied within the structure of a railway company. Nevertheless, there have been numerous simplifications and in this context, minor points of criticism. But taking the limited scope and the fact the model is the first of its kind into account, an overall positive conclusion can be drawn.

However, the current stage of development still demands various further studies and evaluation, such as an extension of the model in both directions – horizontally (a greater number of modules and processes) and vertically (in-depth handling of planning problems through algorithms by means of the field of operations research). Therefore, this work also should be regarded as a foundation for all future attempts at improving the order fulfillment process in rail-bound logistics by means of reference process models and best practices from other industries.

8 Summary

With a transport performance of about 420 billion net ton kilometers, the rail freight sector plays a key role in the European logistics system. However, there is a huge potential for improvement concerning the planning and steering of its order fulfillment processes due to a lack of scientific approaches in this sector. Regarding the predicted growth in the rail freight sector and the harsh competition, especially through the road freight sector, this backwardness ought to be overcome. As there are already numerous best practice process descriptions in the classical (physical) production sector, the overall guideline was to develop a reference process model based on production methods, systems and tools. In order to reach this goal, the transformation of the rail-bound logistics system into a production-based terminology also had to be accomplished. For the validation of the developed model and transformation the medium-sized railway operator DBSR Romania served as a concrete example and platform for a case study.

At the beginning, a meta development model that ensures a consistent approach was introduced. After that, the exact definition of the term *reference process model* was derived. This definition states that reference process models are patterns or blueprints that can be used to develop or improve processes in various fields of economy based on their recommendation character. Subsequently, various sources of production-based reference process models were evaluated in order to create a pool of input processes and expert knowledge for the following development of the reference process model.

However, before the actual development could be undertaken, it required a proper transformation of the rail-bound logistics system to allow the direct application of the production-based terminology. In preparation of the transformation, two further steps were carried out. In the first step, the order fulfillment process in the classical production sector was described in order understand how the reference process model has to be aligned and which elements are important to it. Here, the order fulfillment process was introduced from two perspectives: the commercial and the technical. While from the commercial perspective the order acceptance process was relevant, from the technical perspective the master production schedule planning, the material requirement planning, the resource deployment planning, the detailed scheduling, the production initiation and the production monitoring have been identified as the main elements of the order fulfillment process. These elements (in the same order) also make up the basic structure (or the architecture) of the process flow of the developed model.

In the second step, patterns of the order fulfillment process have been introduced. These patterns can be used to classify each production system, or its order fulfillment process, based on three different criteria types: output related criteria, process related criteria and input related criteria. With the introduction of these patterns, the major tool for the transformation was built up.

In the following part, the rail-bound logistics systems and its orders were described and subsequently transformed into a classical production terminology by means of the patterns. For that purpose, a dictionary that defines synonyms and analogies between both systems and order types also was created. A summary of the most important requirements of the rail freight sector order fulfillment process from the classical production point of view, also represented the basis for the following development of the reference process model.

Starting with the actual development of the model, in a first step the architecture (the first level) of the model was illustrated based on the previously defined general process flow of the order fulfillment process. The architecture was defined through connected modules that refer to certain business cases in the context of the basic procedure. These modules have been identified by tracing the basic steps of the order fulfillment process and the existing order types in the rail-bound logistics: wagonload transport orders (transformed into make-to-stock orders) and trainload transport orders (transformed into assemble-to-order orders). In addition to this matrix, a new module was defined that handles the ordering of infrastructure (i.e. machine or workplace capacity) in the production network. Subsequently, the second level of the model was constructed, using the modeling technique of event-driven process chains. At this point, each module was shaped by detailed process descriptions by both means, textual and graphical illustrations.

Eventually, the model needed to be validated. For that purpose, the model was aligned with the organizational structure and IT landscape of DBSR Romania within a theoretical case study. Through this alignment, a strategic fit was achieved and, finally, it could be proven that the transformation was successful as the application showed that the model was capable of covering the entire order fulfillment process at DBSR Romania.

In the last part of this work, the model, and also the transformation, were positively assessed within the critical acclaim. Even though the scope of this work was limited and numerous assumptions and simplifications needed to be made, the overall goal – the successful development of a reference process model – was achieved. However, it was also pointed out that this work represents rather a basic groundwork that should be extended at many points. It was recommend to conduct an in-depth, practical case study but also to extend the reference process horizontally by more modules. Hence, with this work there also exists valuable basis for further studies that aim at the improvement of the order fulfillment processes in the rail-bound logistics.

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