ASPECT2019///

Improved system modelling for better railway performance

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SUMMARY

The theme of IRSE ASPECT 2019 conference is resilience. Without any doubt, the most challenging issues for today's railway sector are competitive position, performance and cost effectiveness.

The basic point in this paper is the competitive necessity for railways to focus much more explicitly on user perspective. The question is how this fundamental change can be achieved in a technically oriented environment. The introduction of market forces and competition are an important part of EU's railway policy. But it is clear that this policy has its limitations, and in some fields even may lead to higher prices and innovation standstill, because of the fact that railways form a 'natural monopoly'.

In this paper, we first introduce the basics of abstract modelling and system architecture. Then the basics of a user-oriented mobility system model are developed. Elements of the model are re-used from existing abstract system models described in recent railway research publications. The model can bridge the gap between user, governance and technical development, and makes it possible to start system design from the user perspective instead of infrastructure, rules etc. The result can be faster and more effective railway systems innovation.

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1 INTRODUCTION

In the nowadays fast changing world, customer demands and mobility keep on growing. Railways are often seen as too expensive, technically focussed, supply-oriented and insufficiently responsive to the mobility market. The EU recognised this in an early stage, and enforced several measures to re-organise the European railway sector. On technical level, so-called TSI's were introduced to ensure interoperability for seamless cross-border traffic and for increasing infrastructure capacity.

In July 2018, Mr. Josef Doppelbauer, Executive Director of the European Union Agency for Railways, published his vision on the future of railway control and signalling (Doppelbauer 2018b). At the end of the article, readers were encouraged to share their views on the presented vision. This IRSE conference seems an excellent opportunity to present and discuss a paper that addresses some of the strategic points that were stipulated by Mr. Doppelbauer.

It is commonly heard that the railway system is a highly complex system. For some, this is a fascinating aspect. But there is a downside to this: complexity makes a system and its behaviour difficult to understand, especially for those who lack practical operational knowledge and experience. As a consequence, there is a serious risk that changes both inside and outside the system lead to unexpected and unwanted results, such as delays, higher costs, technical problems, decreased performance and safety risks.

In the Dutch railway sector many clear examples of this problem can be observed. One of them is the 2000's SPAD-issue ('Signal Passed at Danger'), analysed by Van den Top (2010). Less systematically described, but commonly known are the Dutch railway crisis in 2001, numeral problems with the Dutch 'High Speed Line South' and the safety software issues at the 'Hoekse Lijn' project. So complexity is not something to be proud of, but something that must be addressed in a professional way. Adequate systems' modelling is the scientific tool to organise this.

In this paper, we start with an introduction into the basics of abstract system modelling, architecture and user-centred modelling. Then we present and analyse three existing models, and finally we built the foundation of the new model. The new model is based on the TU Braunschweig Triangle Model, but several elements from the TU Delft-originating Layer Model and several new ideas are added.

2 ROBUSTNESS VERSUS RESILIENCE & CONTROL

We start this paper with a short remark on the conference's theme: resilience. One of the deeper issues related to the subject of this paper, is that the railway sector historically is a very heavily technical-oriented sector. It started with impressive infrastructure construction works, building stations, laying tracks, engineering big, heavy and overwhelming steam trains, ingenious mechanical signalling constructions etc etc. In these technical area's, it's really all about robustness: make your construction for sure strong enough, multiply it with X to be absolutely sure, and then it's always OK.

This is not what resilience means. Resilience means that you are able to adapt in a quick, co-ordinated and controlled way. We believe that this requires a fundamental change in culture and control. Law or regulations cannot force such. It requires that railways have to re-invent themselves. That is basically what this paper is about: start thinking from a customer perspective – but never ever loose control on technology.

3 BASICS ON MODELLING AND ABSTRACT SYSTEM ARCHITECTURE

3.1 Make the invisible visible

In the next section we are going to analyse some existing railway system models, and start to develop the outline of this new user-centred model that provides a clear and simple view of the *integrated railway system*.

Some readers may wonder why a user-centred abstract railway system model could be useful. Before an answer on this question can be given, it is necessary to understand where modelling *in general* is good for. The answer on that question is basically very simple*: "to make visible the invisible"* or *"to highlight certain aspects".*

A nice example would be a new house that's still in the design-phase. The *architect* can make several drawings of the designed house and show them to the customer. These drawings are in fact models of the future house. Every drawing provides a *view* from a certain *perspective* (Rozanski and Woods 2005). Another possibility is that the architect makes one or more *aspect views*. In an aspect view, a specific aspect has been selected to highlight. Examples could be 'accessibility', 'insulation', 'electrical wiring', 'construction elements' or 'construction phases'. In models, aspect views reduce complexity and so enable you to focus on the aspect that is relevant for you. But it is essential to realise that every model is just a model, and it will never be 100%.

So modelling is basically a tool to make the invisible (or 'difficult to see') visible. Most models highlight certain aspects and reduce complexity with the help of focus, abstraction, systematisation and visualisation.

With this basic knowledge in mind, it is simple to understand where abstract system modelling in railways and signalling is good for: it helps you to reduce complexity and to focus on certain aspects. That is crucial for adequate control of performance, resilience and - first of all - safety.

3.2 Business- and IT-architects

Maybe the reader is already familiar with the fact that nowadays the terms *'architect'* and *'architecture'* are not anymore limited to the (re)design and modelling of physical buildings. In modern business there are specialists called *Business-, IT-, or Software Systems Architect*. In this paper we will explain their activities and added value in (re) design-processes in their domain.

In fact, all architects perform the same tasks: creating adequate models that highlight needs & wishes from users, customers, business and technology, and creating a balanced system (re)design. So the architect helps to 'bridge the gap' between user, business and technology.

3.3 Architectural models for effective governance

In engineering, technical models are intensively used. Many engineers are also familiar with more abstract models like the Deming-circle ('plan-do-check-act') and the Systems Engineering V-model.

In the Systems Engineering V-model, the right side of the 'V' is all about technically building the systems and technical integration of subsystems into the higher level systems. The left side of the V has a different perspective: that side is focussing on abstract modelling, specification and design.

A system architect is mainly active on the upper parts of the left side of the Systems Engineering V-cycle. The system architect tries to find out what the customer and/or business needs are, converts these into models, and also models possible solution architectures. Translated to the railway domain, the high-level design of timetables, infrastructure and the process control system can be seen as architectural products.

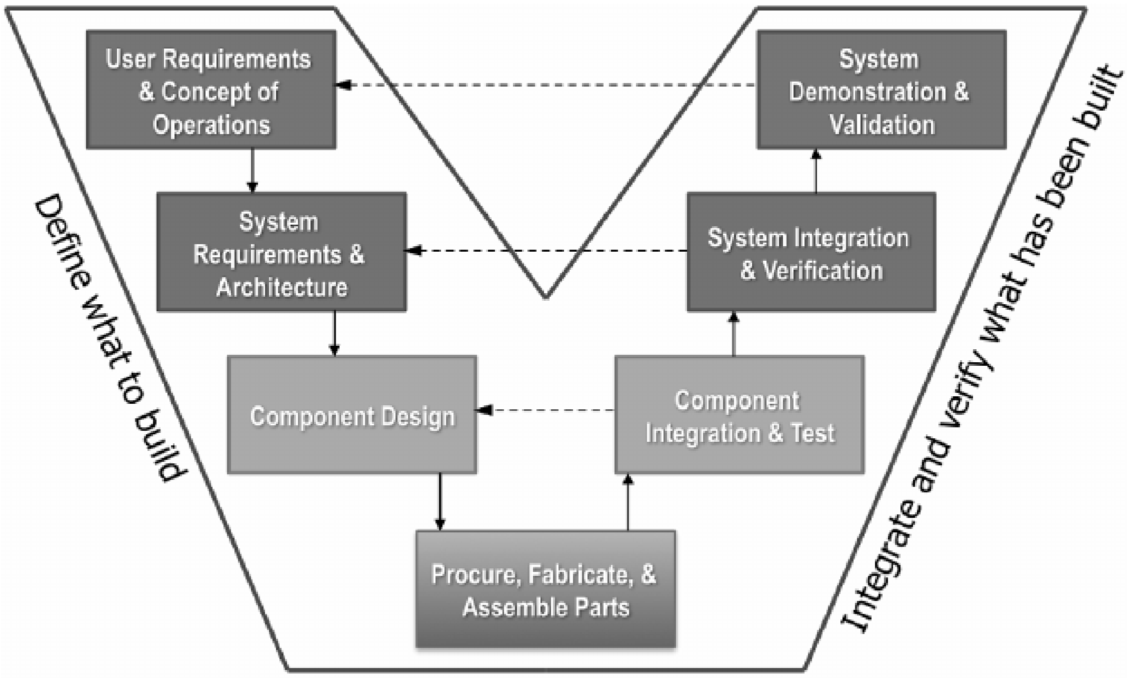

Figure 1: Systems Engineering V-model (source: Sauser 2010).

So the upper left side of the V-model is focussing on *"doing the right"*; the right side is focussing on *"doing it right"*, and the feedback crosslines for test and validation are in fact checking *"did I do it right?"* - and even one step deeper - *"was it really the right thing to do?"*.

Every signalling engineer knows that especially for safety-related systems it is crucial that the design line between 'abstract' and 'detailed' is coherent and systematic. Although the integrated railway system is not that human-lifecritical as signalling and infrastructure is, it is still unwanted that policy makers, managers and other decision makers have incorrect impressions about certain aspects of the railway system.

Therefore, we can conclude that the left side architectural models are important for effective governance: it enables customers, internal users, managers, marketers and other stakeholders to better understand the relevance of certain aspects. Without adequate modelling, most people simply get lost in an overload of details. This is a problem that is very well known in relation to railways. Abstract railway system modelling can solve this.

4 USER-CENTRED RAILWAY SYSTEM MODELLING

4.1 Requirements for a new railway system model

In the new model we want to focus on the integrated railway system. Because railways often depend on other transportation modes for the famous 'first and last mile', we also want to integrate and interface other modes of transportation. And because railways are to a large extent a controlled system, the central position of control of infrastructure and the trains ('mobile transporting part') must be clear.

The relevant system environment, system interfaces and the demand for inter-operability [1] on these interfaces must be clear. Another aspect we want to include in the model is the (possibility of) separation of infrastructure ('IM' or 'ISP' [2]) and transportation ('TOC' [3]). These requirements make the model compatible with EU-regulations.

Before we start to develop the new model, we first give a highly simplified example of abstract mobility system modelling, so the reader already has some idea about the basics of this type of modelling. After that, we analyse three already existing abstract railway system models that were found during a literature study.

4.2 An abstract model example

In Figure 2, you can see the outline of an 'ultimately simplified' user-centred mobility system model. No technical details are included; it is just about the basics. No rails, no roads, no cars: it's just about fulfilling the user who needs a certain object to go from A to B. Maybe himself, a postcard, energy or data. The system could be a railway system, but also the well known *"beam me up, Scotty "* Interplanetary Mobility Solution, or maybe a time machine. So the system could be anything that does transport. The green diamond is the so-called *"Service Access Point"*. In public transportation we would simply call it a railway station or a bus stop.

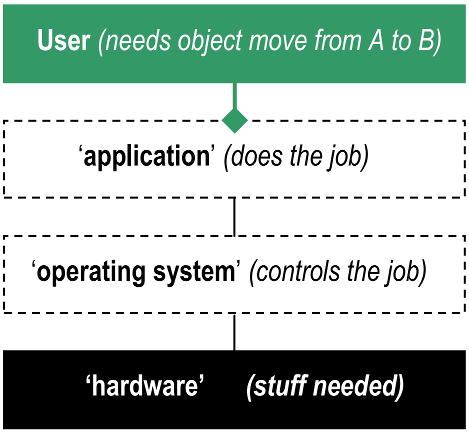

Figure 2 : abstract mobility system model

As you may notice, this model has been derived from the architecture of a standard ICT system. The model fully complies with the principles of the so-called *'OSI Reference Model of Architecture for Open System Interconnection'* (Zimmermann 1980). The example shows that, on a high abstract level, there is no real difference between physical mobility and data mobility. Of course some differences will appear when we make the next step.

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[1] it is important to realise that 'inter-operability' basically means that inter-connected (sub)systems are able to communicate, interact correctly and interacting functions are performed in the required way.
[2] 'IM' = Infrastructure Manager ; 'ISP' = Infrastructure Service Provider
[3] 'TOC' = Train Operating Company

Now we go one step deeper into this model, and add some generic physical mobility elements to it. Of course we think it's fun to make abstract models, but honestly we currently see no good reason for modelling hyperspace-transportation-solutions – we think hyperloop should be sufficient. Therefore we now add the hardware constituents *'infrastructure'* and '*vehicle'* to the model. But we also do another very important thing: we also add the functional perspective of both hardware constituents. These are *'traffic space'* and *'transport space'*.

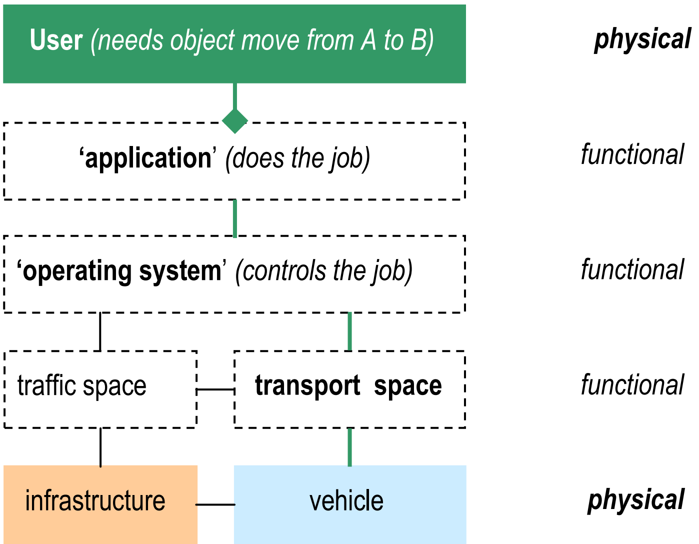

Figure 3 : abstract mobility system model - including basic hardware and functions

There are three relevant aspects on this model we would like to highlight. The first aspect is that the heart of the model is purely functional and has a strict hierarchical structure: on top is the user interface, and the first functional layer is simply fulfilling the user-interfacing task. Within ICT we would call this user-interfacing layer the Application Layer. One OSI layer deeper is the Presentation Layer; that is about the way the user and the system interact. In this simplified model, this interaction is represented by the Operating System. All functional layers below perform technical tasks that are necessary to fulfil the required mobility service. Do keep in mind that all functional blocks are still functional abstractions. At the bottom of the model we come back in the physical world. So the heart of the system is functional and does the job, on top is a human that needs an object (possibly himself) to go from A to B, and on the bottom the two fundamental physical constituents of mobility can be found.

The second remark is about the timetable, an important artefact in railways and public transport. In this simplified model a public timetable would be part of the Operating System. It is essential to realise that, apart from the public Timetable, every user has his own timetable for the requested trip. The user timetable starts at the moment that the user starts with his mobility session (home, work etc.), and ends when the user (or the object) arrives at the destination.

The third remark is that it is also possible that the user walks by himself, or uses a personal transportation solution. In that case the user still needs movement space or traffic space. The 'operating system'-function is then represented by law and regulations, plus traffic knowledge & experience and body functions of the user.

With this introduction into abstract mobility system modelling, the reader should be ready for the next section in this paper: the analysis of three already existing models.

5 ANALYSIS OF EXISTING ABSTRACT RAILWAY SYSTEM MODELS

5.1 Introduction

Classic railway systems modelling is heavily tied to physical objects views. The differentiation in the models is the focus on a certain aspect, e.g. specific area, subsoil, track, signalling, traffic control, cabling etc.

An interesting example for the reader may be the handbook 'Das System Bahn' (Lübke et al 2008). Chapter 7, 8, 10 and 13, focussing on production, business planning, business control and economy, form an exception: many abstract system models are used – which is of course not surprising when taking the focus of these chapters into account. Nevertheless, an abstract 'toplevel railway system model' was not identified in this handbook.

A recent literature study, performed as part of writing this paper, indicated that several authors related to TU Delft (Bovy and Minderhout 1996, Bockstael-Blok 2001, Schaafsma 2001 & 2005), Van den Top (2010), ProRail (Bokhorst et al 2018), TU Braunschweig (Bosse 2010, Scheidt 2017) and the author of this paper (Sierts 2007) have been active on developing and using abstract railway technical system models. [4]

In the PhD-thesis of Schaafsma (2001), an extensive overview and 'pro & cons' -analysis of earlier work on abstract transport layered models has been given. Although this thesis is in Dutch, the provided overview could also be interesting for non-Dutch readers. For practical reasons, we will start the analysis of existing models in 2001.

5.2 Triangle-model (TU Braunschweig)

The picture below shows the basic version of the TU Braunschweig's Triangle-model [5]. The red part represents *physical infrastructure*, blue represents *trains*, green *railway business* and yellow *technology for control and signalling*. The model is very simple and easy to understand, and the structure of the model clearly shows that the business (including business control) is in the heart of the railway system. The difference between infrastructure and vehicles is also clear.

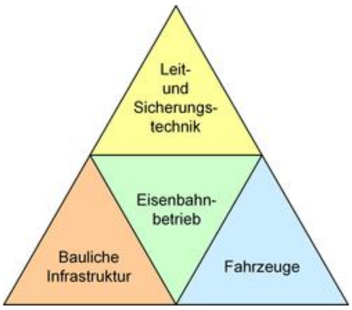

Figure 4: Triangle-model TU Braunschweig - Bosse (2010)

A strong aspect of the Triangle-model is the central position of the so-called "Eisenbahnbetrieb', which can be translated to 'business', including aspects like business control, business rules, process control etc.

The model seems to suggest that there is still one (dominant) operator for infrastructure and trains, because there is only one 'Eisenbahnbetrieb'. This may be correct for the German situation, but for e.g. the Dutch and English situation this could be a problematic simplification. The business of an Infrastructure Service Provider (ISP) is obviously different compared to Train Operating Companies (TOCs).

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[4] Because of the limited character of the literature study, it is possible that there are more publications in this field available. Readers are encouraged to attend the author on other relevant publications via <aspect2019 [at] micopmodel.com>

[5] More information can be found via https://www.tu-braunschweig.de/ifev/lehre

5.3 Generic Transport Layer Model (Schaafsma - TU Delft / ProRail)

Figure 5 shows the basic version of Schaafsma's Generic Layer Model (Schaafsma 2001, translated by Bovy and Van Nes 2004). The blue coloured framework has been added to the original model to highlight the core of the model: the primary service chain.

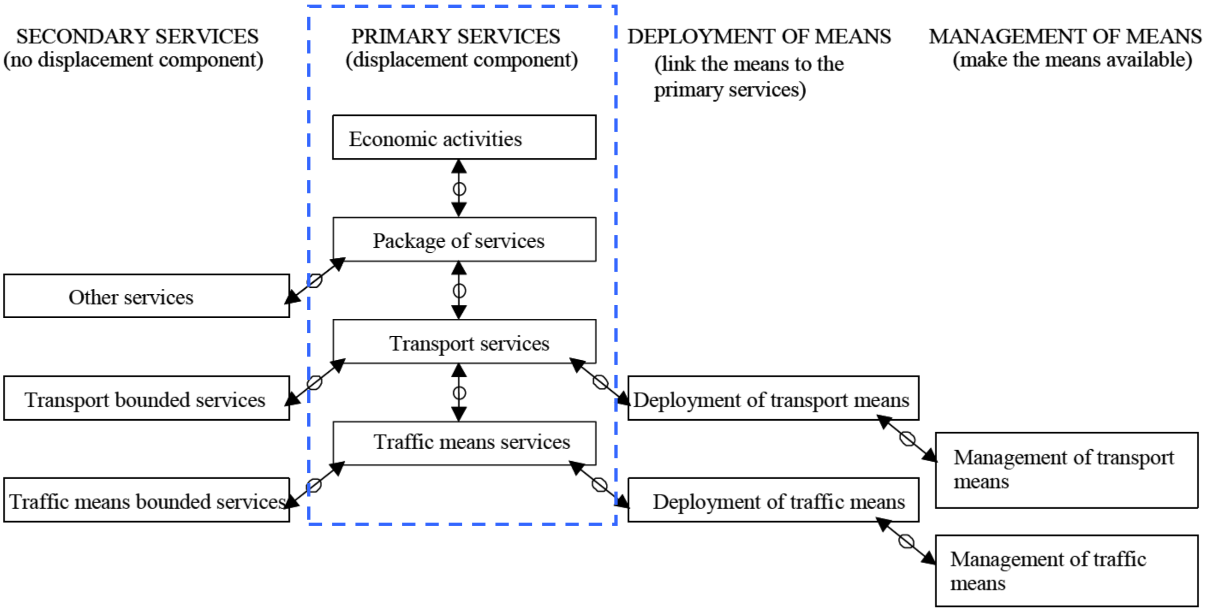

Figure 5 : Generic Layer Model – Schaafsma

The initial transportation layer model, published in 1996 by Bovy and Minderhout (1996) as part of a governmental research project on telematics application in traffic and transportation, is inspired by the OSI layer model (Zimmermann 1980), a model that can be seen as one of the fundamentals behind open system communication standards. Schaafsma added many service elements to the model, as can be seen in figure 5, e.g. the service layer 'Package of Services' and the colums 'secondary services', 'deployment of means', and 'management of means'.

The model can be seen as a major step in the evolution of abstract railway system modelling: in the model the *'switch'* is made from *a 'physical objects view'* towards a *'chain of processes'* and *'services chain'* views.

Schaafsma's 2001-model has been adapted several times, also by the author himself (Schaafsma 2005, Bokhorst red. 2018). Also scientific criticism on the model has been found: Van den Top (2010) listed in his PhD-thesis some inconsistencies in the Generic Layer Model, e.g. the fact that abstractions like 'actors' and 'services' are not consistently modelled. To solve this, also Van den Top modified the model. In the earliest phase of the transport layer model (Bovy and Minderhout 1996), Oude Luttighuis (1997) also criticised some details in the way the layering concept was used.

It is fully clear that the model is strongly influenced by Dutch national and European railway policy in the period around 2000; in that time period separation and privatisation were *'hot topics'*, also in Schaafsma's PhD-thesis (2001).This might explain why Schaafsma modelled several *'outsourcing possibilities'* and *'potential markets'*.

Of course the position of infrastructure ownership has serious impact on the controllability of the production element 'infrastructure'. In case that the infrastructure is not owned by the TOC, the TOC is confronted with much more uncertainty about the deliverability of the required path. In the TU Braunschweig Triangle model, this potentially service-impacting aspect is 'hidden' in the block 'Eisenbahnbetrieb'.

5.4 Extended Cascade Model (Van den Top - TU Delft)

In this model essential control aspects are detailed. It can be seen as a control chain in time, starting with strategic business decisions, and finalising with operations analysis. So in fact the Cascade Model is a more detailed model of the 'green' element in the Triangle-model. The model addresses many business control aspects in a systematic manner.

Another interesting point is the similarity with the Systems Engineering V-model: at the point where the V-cycle would 'flip upwards' (production of means & services), the cascade-model continuous downwards. Adapting this 'drawing detail' could make the model even stronger.

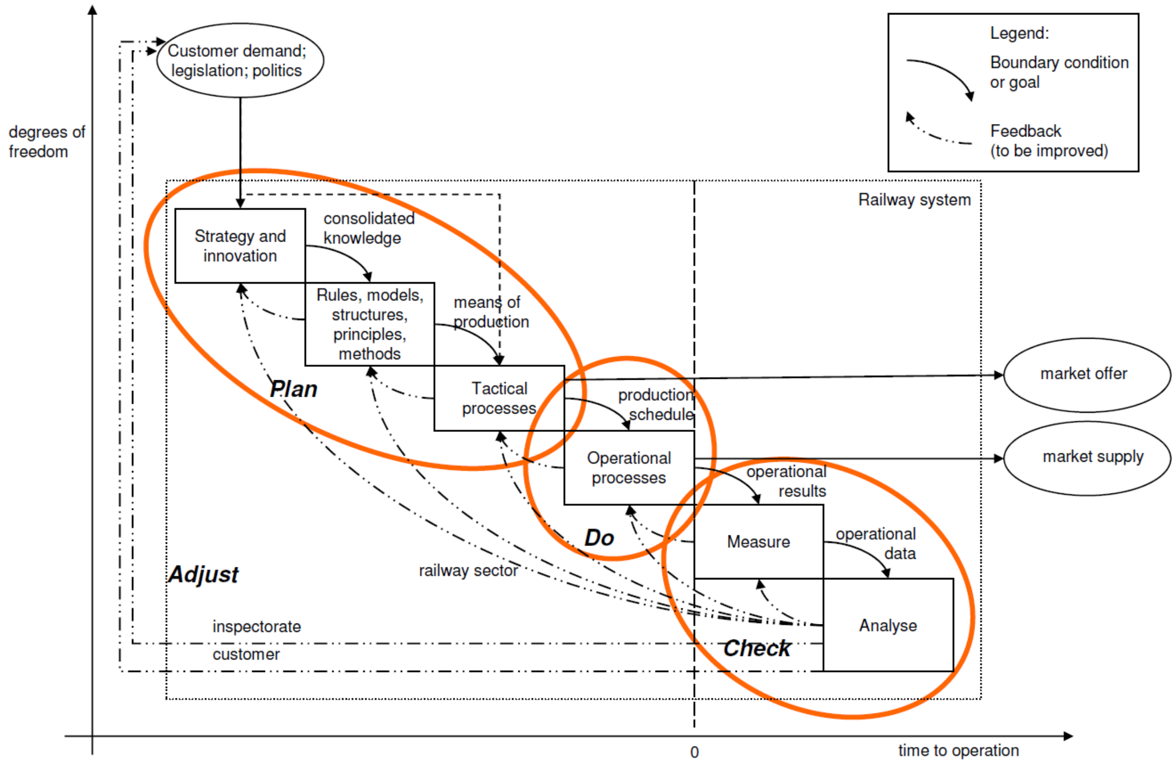

Figure 6: Extended cascade-model - Van den Top (2010)

The most innovate aspect of the Extended Cascade Model is the idea to visualise railway system control fundamentals in a highly abstract way. Physical-technical details have vanished, and the full focus is on system control fundamentals. It is clearly an architectural model.

Another interesting point is that the model has interesting similarities with the Systems Engineering V-cycle model (see Figure 1). The feedback-loops have the same function as the test- and validation-checks in the V-model. In fact the Extended Cascade Model can be seen as an ongoing V-cycle, including service and process design, and continuous evaluation of rules, models, structures, principles and methods. This emerged the idea by the author of this paper to use the V-cycle model not only for structured design and engineering of software systems or physical-technical systems, but also on the higher railway system abstractions. This could be a relevant future railway system modelling development.

5.5 Evaluation existing models

In this subsection we will briefly evaluate the three abstract railway system models. The evaluation is based on the author's personal judgement, and is focussed on the specific goal: a user-centred model.

A general conclusion is that all three evaluated railway system models do not model the user perspective adequately. According to the author, this is a serious problem, because railways are a service, and in case of passenger transportation, the user is not 'just handing over a packet for delivery', but the user is personally becoming a part of the transportation process. The current system models still reflect the internal-technical supply-oriented-approach, although significant steps have been made into the right direction.

- The Generic Layer Model (Schaafsma 2001) is getting close to the service delivery control perspective, especially in the modified 2005-version-paper (Schaafsma 2005). Most elements of this model seem suitable for adaptation towards an individual user centred perspective, including transfer, multimodal transportation and MaaS-concepts ('Mobility As A Service').The Triangle-model from TU Braunschweig is excellent as a simple reference model for the basic constituents, including the centrally placed Business Control ("Eisenbahnbetrieb"), but requires a user-oriented extension and a more explicit approach towards processes and service interfaces. These are elements that can be retrieved from the Layer model.

- The Triangle-model from TU Braunschweig is excellent as a simple reference model for the basic constituents, including the centrally placed Business Control ("Eisenbahnbetrieb"), but requires a user-oriented extension and a more explicit approach towards processes and service interfaces. These are elements that can be retrieved from the Layer model.

- The Extended Cascade-model is an architectural model which zooms in on the Business Control element of the Triangle basic model, covering all railway system control stages: strategic, tactical, operational and performance feedback. Also in this model it is not clear how the business separation between transportation and infrastructure is managed. The only way is the feedback-mechanism *("sorry, the requested path cannot be delivered, the only providable solution is …").* How this can be managed adequately on strategic level is unclear. Schaafsma adressed the strategical path planning issue in his thesis (Schaafsma 2001). In the Dutch context there have already been issues related to this matter, e.g. the capacity issue between Zwolle and Herfte Junction: this capacity shortage could have been foreseen easily, but when inframanager ProRail formally detected it, is was way too late. Solving the issue requires many years, because of major construction works needed. In the time between, the service to the customer is harmed. According to the author of this paper, fundamental analysis on this topic is urgently needed.

6 BUILDING THE NEW MODEL

We already concluded that the TU Braunschweig Triangle-model forms a perfect foundation for the new model, but some additions and improvements are necessary to meet the additional modelling requirements. The first adaptation step is that we flip downwards the Leit- und SicherungsTechik [6] - sub-triangle. The main reason for this adaptation is the wish to combine the three basic physical subsystems (red+yellow+blue) towards one ‘physical layer’, with all the business processes running on top of these.This is also done to highlight the common interface between infrastructure, train and CCS [7]. See figure 7.

The top of the Triangle is now symbolising the external service-interface towards the user. The user is simply modelled as ‘Individual Choosing Human’, abbreviated as *‘ICH’*, so this element is multilingual. Do note that the Triangle-model is now functionally identical to the block model of figure 3.

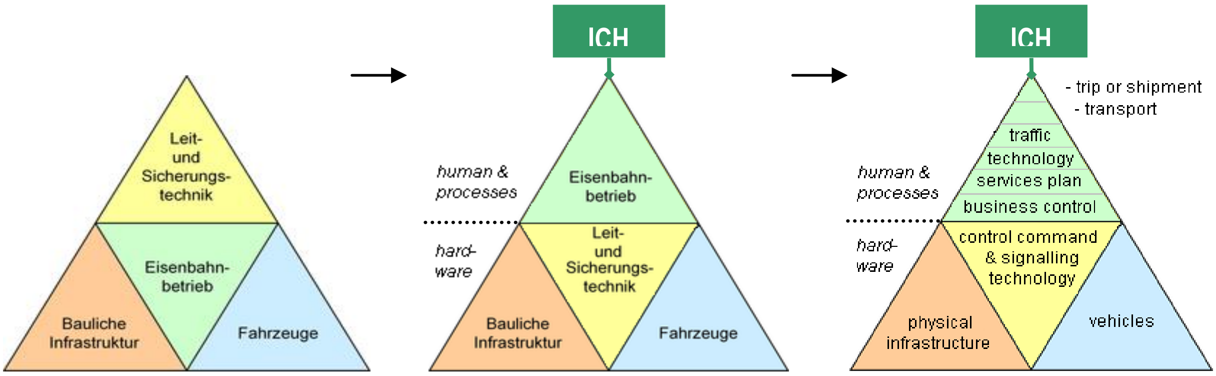

Figure 7: first and second adaptation step Triangle-model

The next step is that we refine the light-green sub-triangle ‘Eisenbahnbetrieb’ with a series of process abstraction layers. Currently we defined the following seven process abstraction layers:

user interface – trip – transport – traffic – technology – services plan – business control

The USER INTERFACE process abstraction is the way the mobility system interacts with the customer.

The TRIP (or shipment) process abstraction is the fulfilment of the movement that the individual user (or its payload) needs. The user timetable is the item that has to be taken care of.

The TRANSPORT process abstraction are all things the train operator (or in generic perspective: the mobility operator) has to perform to realise the TRIP’s for the users.

The TRAFFIC process abstraction is the process of running transporting objects on the infrastructure.

The TECHNOLOGY process abstraction are all the processes that have to be controlled and performed to enable the process layers above. Examples are route setting on interlocking, setting the switches into the required direction, maintenance processes etc. On strategic level also the process of technology evaluation and process innovation can be identified.

The SERVICES PLAN process abstraction speaks for itself.

The BUSINESS CONTROL process abstraction is the heart of mobility business. It controls the upper process layers and - via the consecutive processes – also the three basic physical subsystems.

Do note that the model itself is ‘timeless’ and ‘placeless’ – which might be a bit peculiar for a model concerning mobility. In this model these dimensions are seen as ‘technical details’ that are refined later in the consecutive processes and in the physical-technical abstraction layer.

[6] ‘Leit- und SicherungsTechik’ is German for ‘Signalling & Control’ or CCS
[7] CCS means Control Command Signalling

7 CONCLUSION

With the finalisation of this paper, the foundation of the new user-centred abstract mobility model has been set. The requirement regarding the modelling of separation between infrastructure path supply and transportation is not yet fulfilled, so this is still an open point. Also the multimodal–aspect is something that needs further refinement: the currently developed model is still railway-oriented.

The first following step is to present and discuss the current model at the IRSE 2019 conference and with involved authors/organisations like TU Braunschweig and ProRail Architecture Group. During the IRSE conference presentation some application examples of the developed model will be shown, e.g. multimodal and cross-border trips The limitation in paper length did not allow us to add in-depth application examples to the paper. A future article in IRSE News could be an interesting follow-up option.

Internally we are already working on a next modelling step: the extension and integration of the Systems Engineering V-model for (re)designing the integrated mobility system. This modelling product is assumed to be relevant for Dutch Railforum 'Knowledge Group System Integration' and for the SIRA Research Program at University of Twente ('Systems Integration Railways Advanced").

Feedback on this paper is highly appreciated and welcome @ <aspect2019 [at] micopmodel.com>.

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