Title

Development of a Conceptual Framework to enable the Understanding and Evaluation of Freight Railway Operational Capacity

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CANDIDATE'S DECLARATION

I declare that this research report is my own unaided work. It is being submitted to the Degree of Master of Science to the University of the Witwatersrand, Johannesburg. It has not been submitted before for any degree or examination to any other University.

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(Signature of Candidate)

……02….. day of …October... 2020…………

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ABSTRACT

Operational capacity is an important consideration in Transnet's practical capacity utilisation analysis. Practical capacity utilisation is an important measure in making business decisions as part of Transnet's Long-Term Planning Framework. If Transnet wants to increase practical capacity utilisation in order to attract investors according to the definition of the practical capacity utilisation (i.e. operational capacity as a portion of used capacity) Transnet needs to either reduce used capacity or increase operational capacity. Since Transnet is already facing strained networks, reducing used capacity is not a viable option thus increasing operational capacity is the best way to increase practical capacity utilisation. Operational capacity is theoretical capacity less maintenance and operational allowances and it is this capacity that is the basis of timetable generation. Transnet typically takes operational capacity to be 65% of theorical capacity as a rule of thumb and basis for timetable generation. The proposition of this project is that it is more valuable to determine operational capacity based on the evaluation of a set of timetables, according to stakeholder-valued timetable evaluation metrics. The output of this research is a conceptual framework that can be applied in the evaluation of timetables on the basis of level of risk to achieving the stakeholder valued outcomes. In this way, timetable development, selection and operation depend on the factors of the network that are the most critical to its stakeholders.

ACKNOWLEDGEMENTS

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Lastly, I would like to thank my family and friends for being my pillar through the most challenging days of this experience. Thank you to all for supporting me in making my small contribution to transportation research. I hope that this research adds value to Transnet in its capacity planning activity.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

LIST OF SYMBOLS

Gtkm Gross Tonne Kilometres – the sum of total train weight multiplied by the distance travelled

Mt metric tonne (1)

Ntkm Net Tonne Kilometres – the sum of tonnes carried multiplied by distance carried (2)

Routekm One-kilometre length of route, excluding sidings, without adjustment for double track (2)

1 INTRODUCTION

1.1 Research Background

In Transnet's 30-year Long Term Planning Framework of 2017, it was stated that based on projected demands and current capacity levels, most corridors will face serious capacity constraints within the next decade (3). That is, Transnet faces a significant imbalance between demand and supply; in the freight railway domain, this is known as *the capacity problem* (4) .

Finding suitable aids to addressing the capacity problem is of primary importance to Transnet. As the leading freight rail services provider in sub-Saharan Africa, Transnet aims to provide an efficient transport service, especially as rail faces stiff competition with road transportation, largely due to road transportation delivering higher levels of reliability (5).

When asked what will secure Transnet's success going forward in February of 2019, Transnet Group acting CEO Tau Morwe said that Transnet is working towards an operational model that is fit for purpose and that focusses on efficiencies and an enhanced customer focus (6). Morwe also emphasized the need to utilise the technology and infrastructure already deployed and to eliminate maintenance backlogs while increasing the company's operational discipline (6).

1.2 Research Motivation

1.2.1 The importance of operational capacity and the current approach to evaluating it

Transnet adopts the definition of operational capacity as: capacity in the form of train slots that are available for trains that carry freight to pass through the system (7). The relationship between various types of capacity as defined by Transnet, as they relate to operational capacity is illustrated in Figure 1. A definition of each of the types of capacities follows:

1. Abril, et al. defines **theoretical capacity** as the number of trains that could traverse a route during a specific time interval in a mathematical environment, with trains operating at minimum headway. This forms the upper limit of capacity for a single line (8).
2. Transnet defines **operational capacity** as capacity in the form of train slots that are available for trains that carry freight to pass through the system (3). It accounts for slots required for maintenance and operational allowance. Abril, et al. describes this as the most significant measure of capacity as it captures the *ability* of a specific combination of traffic, operations and infrastructure to move the maximum volume within an expected envelope of service (8). Operational capacity reflects the capacity available when maintenance and operational disturbances are taken into account, within an expected envelope of behaviour for a specific combination of traffic but excludes the allowances based on the condition of the line (author's summary).
3. Transnet defines **practical capacity** as operational capacity less slots required for the condition of the line. where operational capacity reflects the ideal capacity with superb

condition of the line (3). The condition of the line can be affected by things such as vandalism and theft. In addition, sped restrictions can be introduced to manage traffic if there are disruptions on the track. Any day-to-day failures or impairments that affect installed capacity are accounted for here.

4. Abril, et al. defines **used capacity** as the actual traffic volume transported over the network (8). It is always less than operational capacity (9). The part of practical capacity that is left unused is termed by Transnet as 'Available Capacity'. Available Capacity may also be viewed as lost capacity from a business sense as this constitutes potential revenue foregone. Figure 1 provides a visual integration of these capacity definitions.

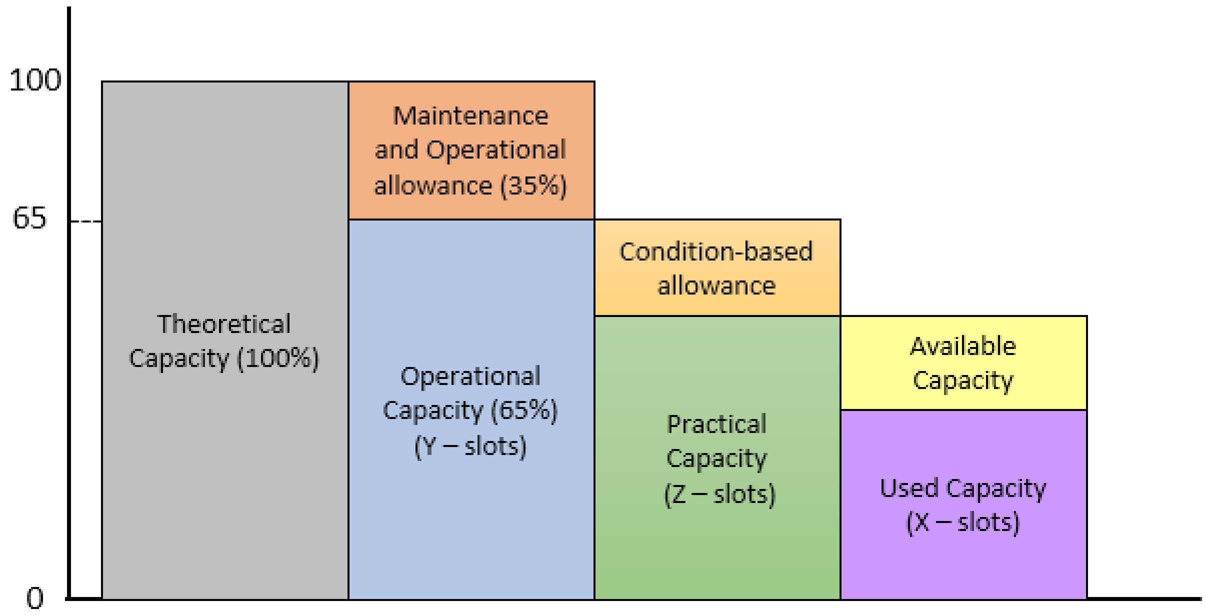


Figure 1: Capacity definition diagram

(Adopted from Transnet, 2017)

Transnet states that operational capacity is determined by calculating theoretical infrastructure and subtracting maintenance and operational allowances arising from external or inherent design issues (3). Transnet also states that when better information is not readily available, the assumption that operational capacity is 65% of theoretical capacity should be used. Abril, et al. state that operational capacity[1] is between 60%-75% of theoretical capacity (8). From this range, we see that globally there is quite a large range of output values for operational capacity as a percentage of theoretical

[1] Abril, et al. uses the term 'practical capacity' to describe the same concept that Transnet describes as operational capacity. Abril, et al. describe practical capacity as the capacity that can permanently be provided under normal operating conditions (8). This is operational capacity in the Transnet environment.

capacity. HDR Engineering states that operational capacity as a 75% proportion of theoretical capacity is typical (10).[2]

As Transnet's definition of operational capacity mentions consideration of maintenance and operational allowances against theoretical capacity, further analysis of assigning maintenance and operational allowances is due. This is covered in the following paragraphs.

Theoretical capacity refers to the number of trains that can physically run over a route whereas operational capacity presents a practical limit to the number of trains that can be operated to maintain a certain level of reliability as is shown in Figure 2. The figure shows an inverse relationship between capacity and reliability. When capacity is lower than operational capacity, reliability increases and tends towards 100% as capacity decreases. When capacity is higher than operational capacity, reliability tends towards zero. There is a trade-off between capacity and reliability: the closer one operates to theoretical capacity; the less reliable operation will be. The less capacity there is, the more reliable operations will be. It is the job of the railway operator to find the sweet-spot of capacity where there is a sufficient level of capacity to sustain a business but also not so high so as to jeopardize reliability as this will affect the customer's interest and long-term sustainability of the business. , There is a region of overlap of acceptable levels of capacity and acceptable levels of reliability which outlines the feasible region of operation (8).

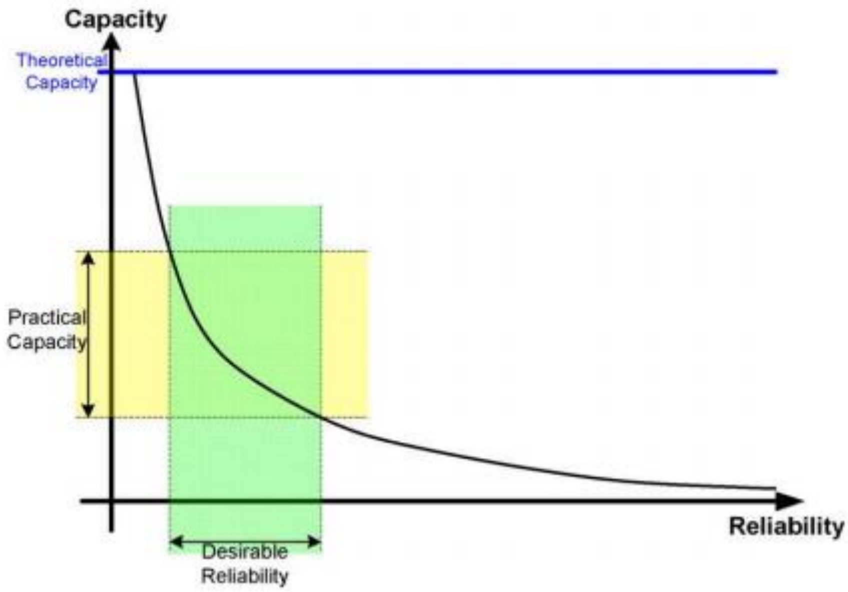


Figure 2: The relationship between capacity and reliability

[2] HDR Engineering uses the term 'practical capacity' to describe the same concept that Transnet describes as operational capacity. HDR Engineering defines practical capacity as the capacity that is available under normal operating conditions which is equivalent to operational capacity in the Transnet context (10)

(Adopted from Abril et al. 2009)

Analysis of the various types of capacity and the elements that contribute to them are outlined in Figure 3. This deconstruction outlines the main elements to be considered when analysing each type of capacity according to Transnet's definition.

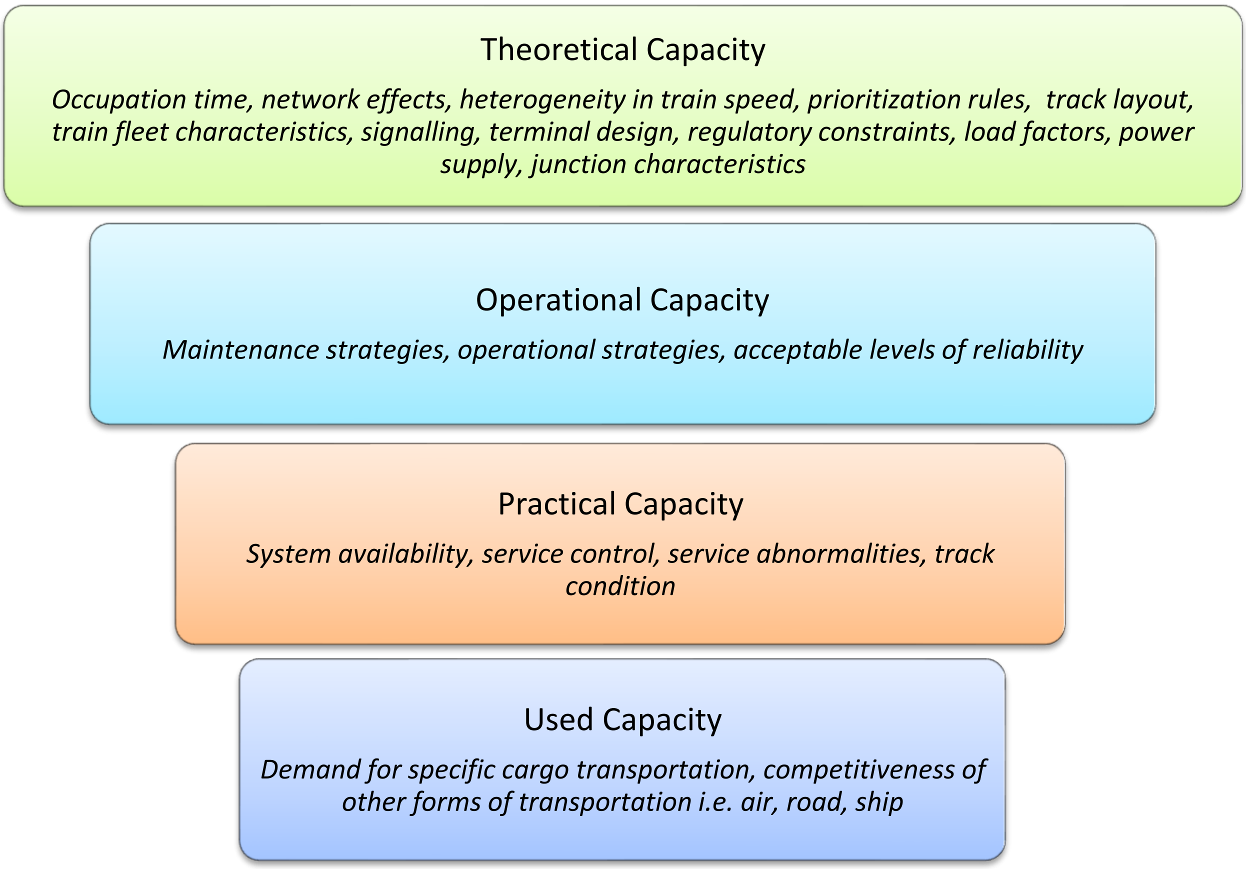


Figure 3: Elements for consideration in each Transnet-defined capacity type

Adopted from (8) (11) (12) (13) (14) (15) (16) (17) (18) (19) (20) (21)

1.2.2 Operational capacity and practical capacity utilisation

Transnet defines practical capacity utilisation as the percentage of used capacity divided by operational capacity (3) [practical capacity utilization (%) = X slots/ Y slots according to Figure 1]. The result of this calculation is used as a major indicator of the condition of the network within Transnet. The interpretation of the percentage practical capacity utilisation is shown in Figure 4.

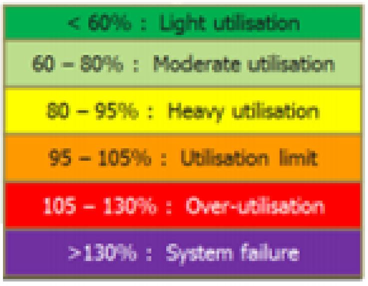


Figure 4: Indicators for practical capacity utilisation

(Adopted from Transnet, 2017)

The utilisation percentile figure is the key driver in deciding whether a section of the network needs to be reviewed or upgraded (5). Clearly, it is ideal for networks to be operating below 100% to prevent poor levels of service and permanent degradation to the equipment.

Based on the formula for practical capacity utilisation [practical capacity utilisation = used capacity/operational capacity], in order to reduce this capacity percentage, either used capacity should be reduced or operational capacity should be increased. Since Transnet faces the challenge of rising demand and diminishing resources to meet that demand, the business-driven option to reduce this utilisation figure is to increase operational capacity.

Operational capacity is a major driver in determining capacity utilisation which influences the effort and resources assigned to building infrastructure for a line. The aim of this research is to provide a means that enables evaluation of operational capacity through careful consideration of relevant operational and maintenance factors rather than routinely accepting operational capacity as 65% of theoretical capacity. Additional motives for exploring operational capacity in this manner are outlined below:

- Calculating allowances due to external or inherent design issues is a not a straight-forward task as a clear description of the external environment and a detailed analysis of the internal structure of the system is required to obtain meaningful results (22)
- Capacity analysis in the railway sector is a very challenging activity due to its numerous interrelated factors, the complex structure of the railway and the extent of terminology needed to address it (23). Any research that contributes constructively to the understanding of capacity and its evaluation benefits the railway industry as it adds to the body of knowledge.
- If operational capacities vary as widely as is suggested by Abril et al. (2008), applying a ‘65%’ rule-of-thumb may not be the best approach when a network potentially has the ability to transport more goods within acceptable levels of service. Conversely, if the network has an actual operational capacity lower than 65% and this is the assumption that is taken, this may result in delays and dissatisfied customers.

This research paper aims to provide an alternative mechanism to evaluating operational capacity, suitable for the Transnet environment and applicable by railway operators throughout the world with some adaptation.

1.2.3 The Application of systems engineering approaches in railway projects

The Institute of Electrical and Electronics Engineering defines systems engineering as an integrative approach that governs the technical and managerial effort required to transform a set of customer needs, expectations, and constraints into a solution and to support that solution throughout its life (25) . Project Performance International describes systems engineering as a set of process elements to be applied in the design of complex systems – these system elements function to increase value and reduce risk to the system's stakeholders resulting in an optimal solution that meets the stakeholder needs (26). The term, 'systems engineering' dates back to the 1900s and its first major application was during World War II (27). Hall describes systems engineering as comprising five phases (28):

1. Program planning
2. Exploratory planning including problem and requirements definition, system synthesis and analysis
3. Development planning (phase 2 in further detail)
4. Studies during development i.e. integration and testing
5. Concurrent engineering while system is operational and is further refined

Since its inception, systems engineering has been documented to have a strong relationship with project success in the fields of aerospace, agriculture, defense and energy (29). Similarly, the transportation industry has embraced systems engineering due to its benefits in aiding decision-making at a relatively low-cost (compared to design, build and test without requirements) (30). Significant successes have been attained in the transportation industry, specifically in the railway sector as is evidenced by several case studies described in the International Council on Systems Engineering (INCOSE) Guide to Systems Engineering in Transportation Projects – A Library of Case Studies (31). Appendix A contains a summary of three such case studies. The Guide provides substantial evidence that using systems engineering techniques in addressing construction and operation-related issues in transportation has been, on the whole, very effective.

1.3 Research Questions and Objectives

In order to produce a valuable output in the form of a conceptual framework, two research questions were posed as an initial step to guide subsequent research. This formed the foundation of the research conducted. The research questions posed were:

- What are the empirical building blocks that need to be considered when understanding and evaluating operational capacity?

- What are the relationships between the parameters comprising these building blocks?

In search of answers to the above research questions, the following research objectives were devised:

Table 1: Project research objectives

	Research Objective
1	Establish a detailed definition of operational capacity and distinguish this from the other types of capacity
2	To identify the elements comprising operational capacity
3	To develop a conceptual framework that illustrates the relationship between the elements comprising operational capacity
4	To validate the developed conceptual framework through engagement with industry experts such as managers, engineers, operators etc.

1.4 Structure of the Research Report

The figure below outlines the structure of this research report and the contents of each chapter.

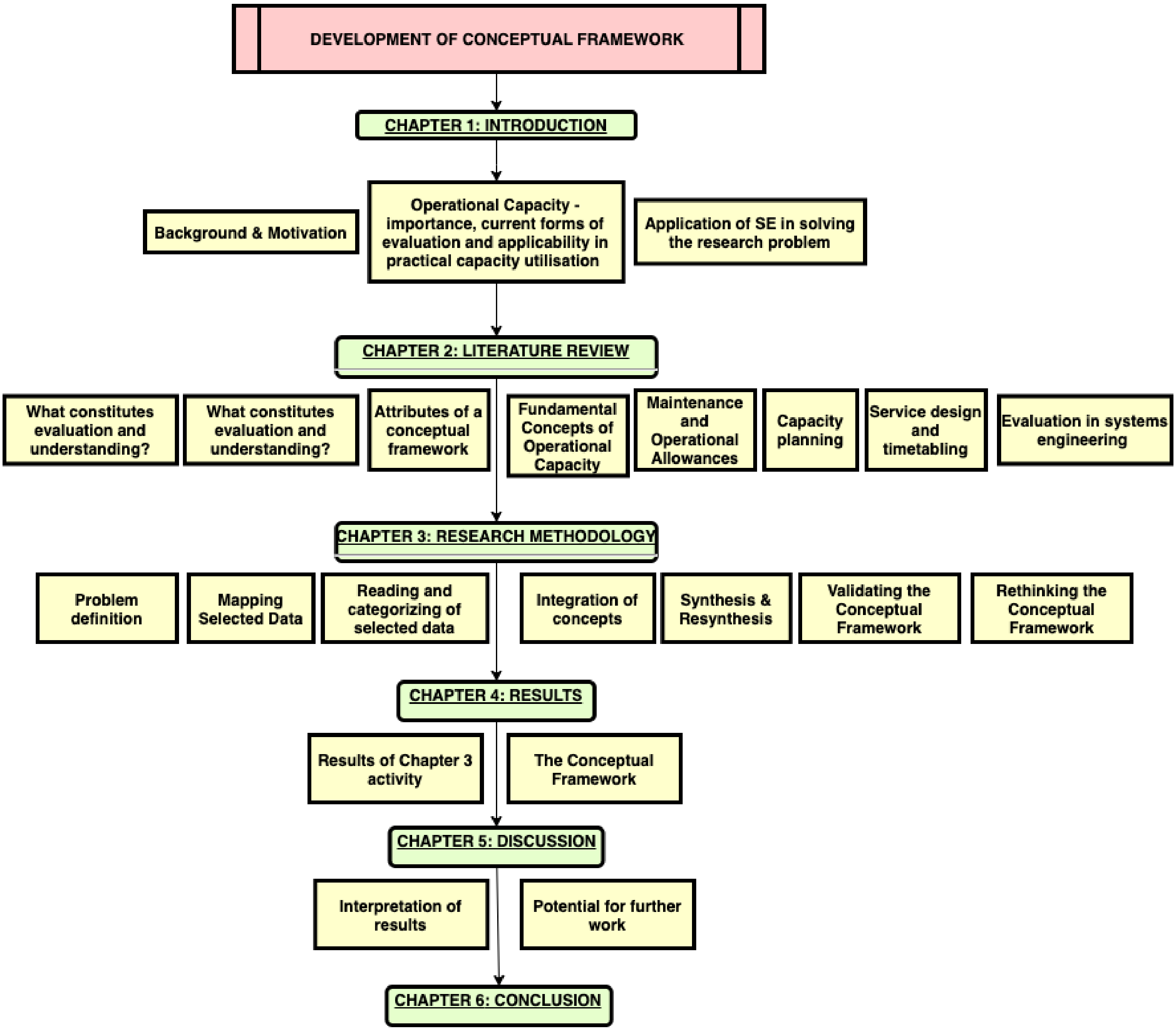


Figure 5: Structure of the Research Report

2 LITERATURE REVIEW

2.1 Conceptual Frameworks

Historically doctoral supervisors have observed uncertainty with students regarding what constitutes a conceptual framework (32). Many supervisors believe this uncertainty results from research methodology texts lacking a language for defining the nature of a conceptual framework (33). Weather-Hart describes conceptual frameworks as ‘a structure for organising and supporting ideas; a mechanism for systematically arranging abstractions; sometimes revolutionary or original, and usually rigid’ (34). Leshem and Trafford state that a conceptual framework is similar to a paradigm in that it defines boundaries and models possible patterns and relationships (33) while Rudestam and Newton state that a conceptual framework, is a less developed form of a theory that links abstract concepts to empirical data (35).

Amalgamating these ideas, conceptual frameworks can be described as maps that link together concepts and empirical evidence in a way that captures patterns and relationships pertinent to the research issue (author's deduction). This is echoed in Robson's motivation for why a conceptual framework would be developed in the first place: 'developing a conceptual framework forces you to be explicit about what you are doing. It also helps you to be selective and decide which are the important features; which relationships are likely to be of importance or meaning; and hence what data you are going to collect and analyse.' (36).

Typically, conceptual frameworks are used in research to optimally present a research question in order to drive investigation (37), however in this research project, the significance of the conceptual framework is to enable understanding and evaluation of freight railway operational capacity. The difference being in that the conceptual framework in this research project follows and not precedes research design and conduct.

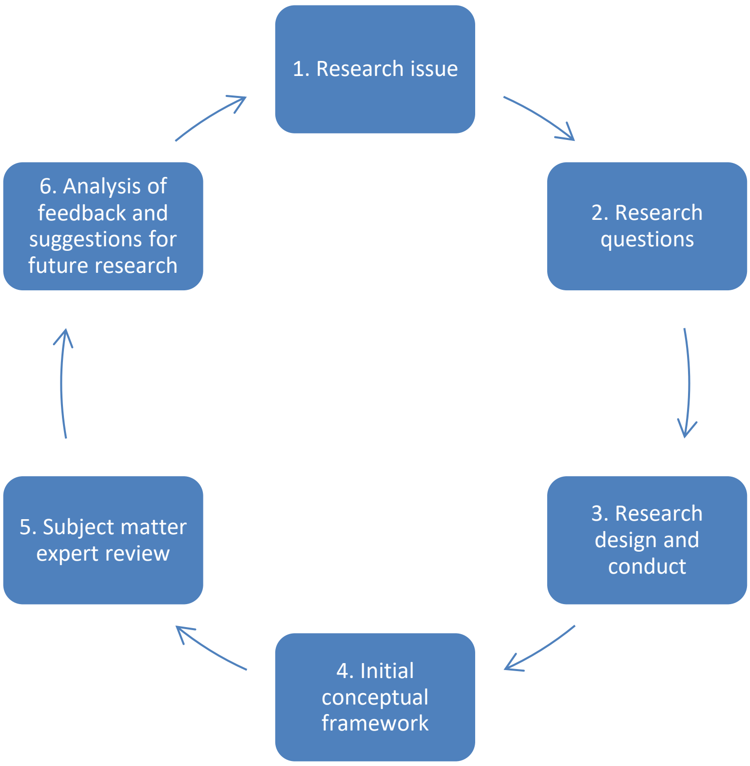


Figure 6: Visualising the research process

(Adapted from Glatthorn and Blackmore (38) (32))

Specific forms that conceptual frameworks can take include flowcharts, web diagrams, other schemata, Venn diagrams, conceptual modelling shapes and others as potential forms for capturing the framework conceptually (38) (32).

2.2 Characterising 'Understanding' and 'Evaluation'

The main purpose of this research is as captured in the title, to develop a conceptual framework that enables understanding and evaluation of freight railway operational capacity. In order to ensure that the purpose is fulfilled, a clear scope of what constitutes understanding and evaluation must be achieved.

2.2.1 What constitutes understanding?

Merriam Webster defines understanding as, ‘the capacity to apprehend general relations of particulars’ and ‘the power to make experience intelligible by applying concepts and categories’ (39). Perkins states that these relationships should be extrapolated from experience, evidence and sound analogies to other scenarios (40). By nature, conceptual frameworks foster understanding if they are developed according to a structured methodology (41).

2.2.2 Evaluation within the context of systems engineering

The purpose of this section is to define systems engineering and expound on its value. A number of definitions of systems engineering have been embraced in engineering. A set of five such definitions are presented below and their similarities and differences are discussed.

1. The International Council on Systems Engineering (INCOSE) defines Systems Engineering as *a transdisciplinary and integrative approach to enable the successful realization, use, and retirement of engineered systems, using principles and concepts,* and scientific, technological, and management methods. Here the terms, ‘engineering’ and ‘engineered’ are used in their widest sense: “the action of working artfully to bring something about”. “Engineered systems” may be composed of any or all pf people, products, services, information, processes, and natural elements (42).

2. Fabrycky describes systems engineering as the iterative and integrative application of analysis, synthesis and evaluation shown generically in Figure 7 (15).

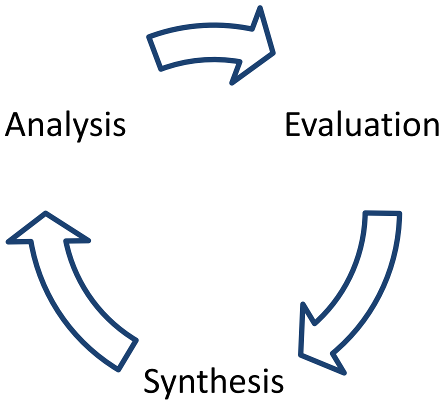


Figure 7: Synthesis, analysis and evaluation

Adopted from Farbycky **(15)**

3. The Department of Defense (US DoD) defines systems engineering as a logical sequence of activities and decisions that transforms an operational need into a description of performance parameters and preferred system configuration (43)
4. The Electronic Industries Alliance (EIA) defines systems engineering as the interdisciplinary approach that encompasses the entire technical effort, and evolves into and verifies an integrated and life cycle balanced set of system, people, products, and process solutions that satisfy customer needs (44)
5. The Business Dictionary describes systems engineering as the systematic effort to translate an operational need into system performance and configuration specifications, incorporate all physical and functional requirements to achieve an optimal design and integrate factors such as maintainability, reliability, safety and security to meet cost, performance and schedule objectives (45)

The definitions above share similarities regarding a life-cycle concept, starting from a point of having a set of stakeholder needs and working through systematic a process to provide a system solution. All the definitions speak to the concept of interdisciplinary approaches throughout this process. The Business Dictionary and the US DoD mention the significance of establishing performance parameters, in relation to customer requirements. The Fabrycky definition introduces the concept of iteration being fundamental to the process which is not emphasized by the other definitions. The Business Dictionary also brings about the concept of finding an optimal design which is also not emphasized in the other definitions. Of particular significance amongst these definitions is the concept of the life cycle. A system life cycle is an organizational process of developing and maintaining systems (46). There are a multitude of system life cycle models adopted by different industries, products and services. The system life cycle shown in Figure 8 applies to asset management and can be applied to the instance of rail infrastructure asset management. In application, all three aspects: analysis, evaluation and synthesis are apparent throughout every stage of the system life cycle.

Figure 8: Asset management system life cycle

Adopted by Atkins Global (46)

Evaluation is strongly connected to decision making and selecting the best alternative, based on the stakeholder needs (26). Farbycky states that for suitable system cost structuring and effectiveness, decision support in the form of evaluation and analysis is essential (15).

2.2.3 Attributes of a useful conceptual framework

Bringing the above aspects of conceptual frameworks, understanding and evaluation together, the output of this research should be a conceptual framework in the form of a flowchart, web diagram, Venn diagrams, or other conceptual schemata that:

A. Explains the concept of freight railway operational capacity
B. Links empirical findings on particulars to abstract, general concepts associated with freight railway operational capacity
C. Captures relationships between important freight railway operational capacity concepts
D. Highlights analogies to other scenarios in order to facilitate understanding of freight railway operational capacity
E. Incorporates insight based on experience and
F. Enables comparison and selection from evaluation artifacts related to freight railway operational capacity.

This provides a context for further development. There is strong alignment between the research objectives and the aspects required of the conceptual framework. Table 2 highlights the relationship between:

1. the research objectives set out at the start of the project (see **Error! Reference source not found.**) – column 1
2. the attributes to be demonstrated through the conceptual framework – column 2
3. the sections of this research report in which these attributes are covered – column 3

Table 2: Alignment between research objectives and attributes of the conceptual framework

	Research objective by number	***Demonstration through conceptual framework (above) by letter***	***Section addressed in report by paragraph number***
1	Establish a detailed definition of operational capacity and distinguish from the other types of capacity	Explain the concept of freight railway operational capacity (A) Highlight analogies to other scenarios in order to facilitate understanding of freight railway operational capacity (D)	Freight (Section 2.3.1) Type of capacity (Section 2.3.2) Capacity metrics (Section 2.3.2) (Case Studies of SE Application in Railway Projects)

			(Appendix A)
2	To identify the elements comprising operational capacity	Explain the concept of freight railway operational capacity (A)	Operational Capacity (Section 2.3.4) Overview of contributing elements to capacity (Section 2.3.5)
3	To develop a conceptual framework that illustrates the relationships between the elements comprising operational capacity	Link empirical findings on particulars to abstract, general concepts associated with freight railway operational capacity (B) Capture relationships between important freight railway operational capacity concepts (C)	Capacity metrics (Section 2.3.2) Timetabling (Section 2.4)
4	To analyse the causal relationships between the elements of the railway network	Capture relationships between important freight railway operational capacity concepts (C) Highlight analogies to other scenarios in order to facilitate understanding of freight railway operational capacity (D)	Capacity planning (Section 2.3.7) Timetabling (Section 2.4) Integration of Concepts (Section 4.4) Synthesis, Resynthesis - Making It All Make Sense (The Conceptual Framework) (Section 4.5)

5	To validate the developed conceptual framework through engagement with industry experts such as managers, engineers, operators etc.	Incorporate insight based on experience (E)	Mapping of the Selected Data Sources (Section 4.1) Validating the Conceptual Framework (Section 4.6)
6		Enable comparison and selection from desirable candidates related to freight railway operational capacity (F)	Systems Engineering Approaches to Evaluation (Section 2.6) Synthesis, Re-synthesis - Making it All Make Sense (Section 3.6)

2.3 Fundamental Concepts in Freight Railway Operational Capacity

2.3.1 Freight rail capacity definition

Early stages in the critical literature review process highlighted the vast difference in language surrounding freight railway capacity in all respects, including in capacity definitions and related concepts. In fact, extensive internet-based research showed that the term ‘operational capacity’ was found not to be a term used in the freight railway industry outside of the Transnet environment. Lindfeldt acknowledges the lack of consensus in definition of capacity-related terms (18). UIC states that this variation in taxonomy results from different railway environments having different capacity needs however this mismatch of needs leads to different interpretations and a general misunderstanding (47). Roberts et al. state that this lack of clarity in capacity definition means that railway operators struggle to determine whether a network has reached capacity as the attributes most critical to capacity constraints are not obviously apparent (20).

Nevertheless, some widely referenced definitions of capacities as determined by number of references in published journal papers are:

- Kahan describes capacity as The ability of the carrier to supply as required the necessary services within **acceptable service levels and costs** to meet the **present and projected demand**.” (48)

- Krueger describes capacity as“the highest volume (trains per day) that can be moved over a subdivision **under a specified schedule and operating plan** while not exceeding a **defined threshold**.” (49)

- Kieran describes capacity of a track by “the number of trains that will cause the system to lock up”. “Track capacity is **not constant but variable with prevailing conditions**” (50)

- Barkan and Lai describe capacity as “the measure of the ability to move a certain amount of traffic over a defined rail corridor with a **given set of resource**s, under a specified service plan, known as level of service.” (51)

- Tolliver describes freight rail capacity as “the number of trains per day for **typical track configurations** depending on several factors, such as track segment length, train speed, signal aspects and signal block length, directional traffic balance, and peaking characteristics” (52)

The above definitions highlight the concepts of acceptable service levels and costs, a limited set of resources, track configurations, present and projected demand, schedule and operating plans, defined thresholds and variability on the basis of conditions as being paramount considerations in capacity definition.

2.3.2 Type of capacity

Capacity can be deconstructed into various types on the basis of location, calculation method and degree of utilization (18). The various types are defined below (8):

- ‘Location’ relates to the section/position of the railway network for which the capacity is calculated
- ‘Capacity assessment’ is concerned with the way in which capacity is quantified – by calculation or by degree of utilisation.

A breakdown of capacity according to these terms is outlined in

Table 3.

Table 3: Breakdown of capacity terms on the basis of location, calculation method and degree of utilisation (8) (47) (11) (53)

Location (scope of capacity analysis)	**Capacity Assessment**	
	Calculation method (typically calculated via simulation or parametric calculation)	*Degree of utilisation*
Network Capacity (includes multiple lines and terminals – e.g. open structure) The amount of traffic/cargo that a network can process	**Theoretical Capacity** Maximum traffic/cargo physically possible to process under ideal conditions	**Used Capacity** Actual amount of traffic/cargo that is processed
Terminal Capacity The amount of traffic/cargo a terminal can process	**Practical Capacity[3]** The amount of traffic that/cargo that can be processed under normal operating conditions – with expected level of service *(most closely related to operational capacity)*	**Available Capacity** Amount of traffic/cargo that can still be processed
Line Capacity (e.g. closed structure) The amount of traffic/cargo that line can process		

[3] **Practical capacity* (as used by (8), (18) and (131) is the term most closely associated with 'operational capacity' as defined by Transnet since both terms consider capacity under normal operating conditions, on a long-term basis. In essence, operational capacity points to a calculation method within the capacity assessment type.

Throughout the research report, network (combination of lines and terminals) is most commonly referred to as it applies to the largest boundary of consideration when studying a railway segment.

The value of clarifying the type of capacity according to location and capacity assessment is that it demarcates the system boundary of the system of interest (SOI)The systems boundary demarcates a limit to the system's internal components and processes – it defines some subset of reality under study that the system analyst presumes there is sufficient degree of control over and therefore can measure, analyse and draw conclusions about performance of the SOI (54). Outside of the boundary is the system environment – the system environment provides inputs and consumes outputs of the SOI. In Figure 9, the System-in-Focus or (SOI) receives inputs and outputs from sibling systems which form part of the environment.

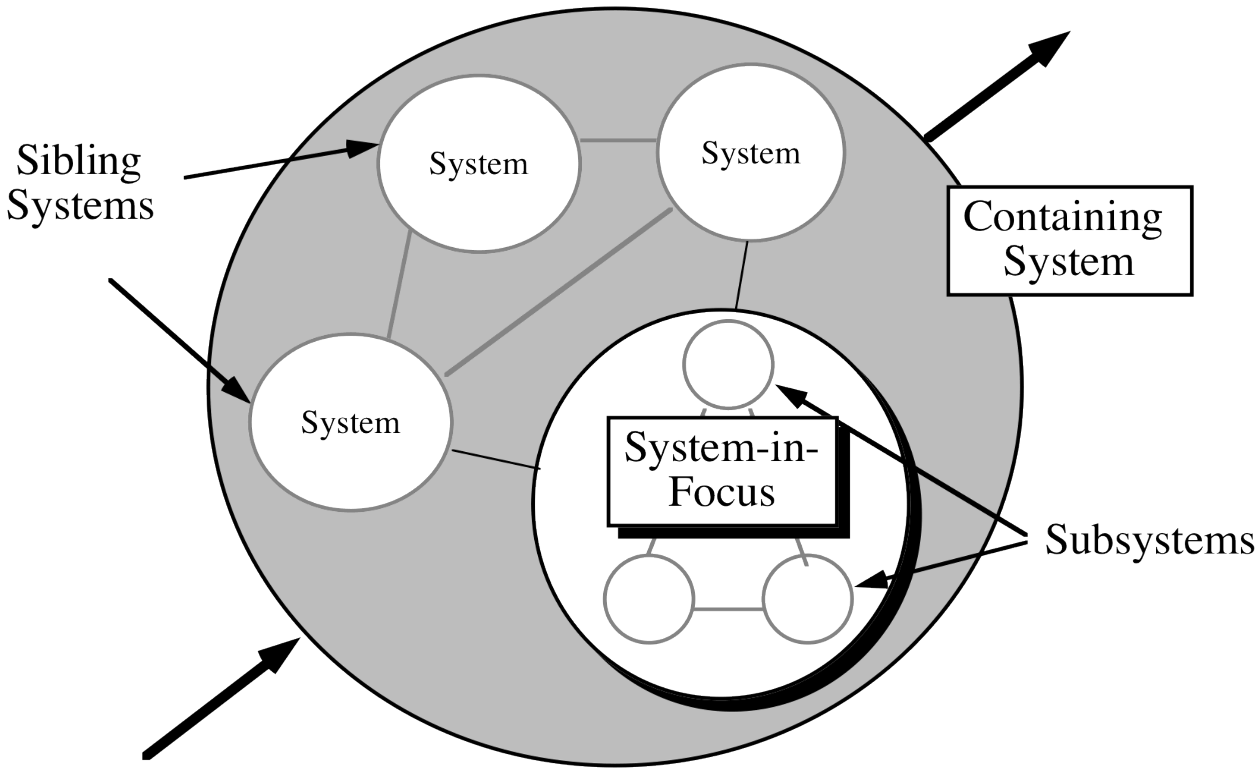


Figure 9: The 'Poached Egg' diagram

(Adopted by (55)

There are open systems and closed systems – open systems have a high rate of input and outputs to the systems i.e. they are dynamic (55). Closed systems have much lower rate of transfer of data or resources across the system boundary, they are static (54). In Figure 9 above, an open system would have a high rate of interaction with sibling systems whereas a closed system would have a very slow rate of interaction.

2.3.3 Capacity metrics

Regardless of the type of capacity under study, capacity is a factor of the entire system configuration which includes track and terminal infrastructure, the signalling system, the operating strategy and rolling stock (56). The level of capacity is assessed according to a metric (or set of metrics). Three broad types of capacity metrics are frequently used in the freight railway industry namely throughput, level of service and asset utilisation (8). The metrics used in capacity assessment will be selected based on the interests and prioritization of the relevant stakeholders (18). Table 4 outlines the definition and utility, limitation and stakeholder of relevance for each of the three capacity metrics.

Table 4: Capacity metric definitions, limitations and stakeholder Interest

(56) (8) (57) (53) (20).

Metric	Definition and Utility	Limitation	Stakeholders and their interest	Example units of measurement
Throughput	Direct measure of how much material is transported over a route in a specific unit of time (in terms of trains, cars and tons)	Highly influenced by train and car types[4]	Rail service providers as they are concerned with maximising profit	Trains per hours (TPH)
Level of service	Measure of reliability and timeliness, typically in terms of dwell time and train delays	Depending on the indicator chosen, this metric may take a long time to acquire if it relies on feedback from customers or other stakeholders	Shipping companies and investors as they are concerned with quality of service (especially in competition with other freight transportation modes)	Average delay per train (minutes or hours) or percentage of secondary delays caused by first delays (minutes or hours)
Asset utilisation	Use of infrastructure, rolling stock,	Does not give an indication of quality of service	Investors as they are concerned	The mass of the train divided by the

[4]Effect of train characteristics on capacity from the various metric perspectives is discussed in **Error! Reference source not found.**

	motive power and personnel	or condition of assets during service	with efficient use of assets	mass of goods transported by the train

Robert el al. affirms that metrics selected for assessing the capacity of the railway network will depend on what the goal of the railway operation is (20). Different stakeholders will have different viewpoints (interests) of the railway network. Cloete-Hopkins used the Ministry of Defence Architecture Framework (MODAF) to capture the viewpoints for the transportation sector (see Figure 10). These apply in large part to Transnet's freight rail operations.

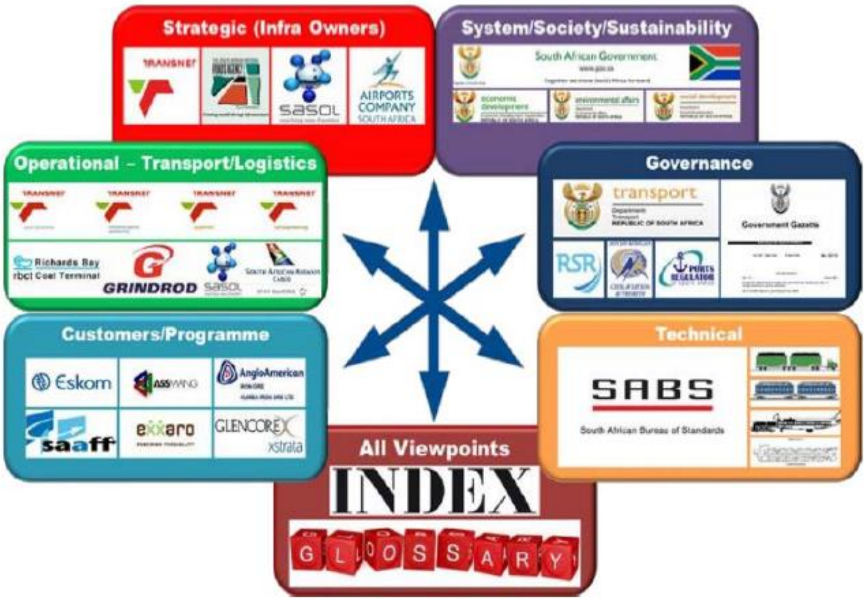


Figure 10: A visual presentation of the MODAF views (or stakeholder perspectives) in in the transport sector

(Adopted from (58))

Using the content of Table 4 as a reference, Transnet's operating divisions may be concerned with throughput as a metric for capacity, while SAAFF (the South African Association of Freight Forwarders) may be concerned with level of service metrics and Sasol as an infrastructure owner may be concerned with asset utilisation (for example).

It is worth noting that for the Transnet case, Transnet is the owner/operator of the freight rail network but Transnet's priorities should be considered from these two perspectives, separately since ownership requires a more strategic (long-term) view while operators, in general will be concerned with more short-term business concerns (59).

The wide range of stakeholders with an interest in freight railway capacity is one of many aspects that contributes to the complexity of the railway system (4). Freight railway networks are considered to be highly complex environments due to (60):

- the large number of concerned stakeholders
- a high-stakes environment
- uncertainty in terms of future events
- a large number of perspectives and disciplines
- an evolving nature of affairs
- the simultaneity of possible interventions to address the problem e.g. geographic, governmental, social etc

Systems engineering provides a set of analysis techniques to deal with the complexity of catering to stakeholders. One example of a stakeholder analysis technique is the use of utility functions which provides a mechanism for conducting trade-offs between parameters of importance to stakeholders (see section 2.6.1 for further detail on utility functions and their role in evaluation in selection the best option out of a set of candidates, based on stakeholder-valued outcomes.)

Systems engineering has provided substantial evidence in recent decades to deal with scale, interdependency and complexity throughout the system lifecycles of defence and transportation systems (61). The complexity of the freight railway system, makes railway capacity a good candidate for applying a systems engineering approach to its analysis (31).

2.3.4 Operational Capacity

As stated in Section 1, Transnet defines **operational capacity** as the capacity in the form of train slots that are available for trains that carry freight to pass through the system. Operational capacity may be considered as the capacity that is available on a permanent basis due to realistic expectations of maintenance and operation[5]. Krueger states that this capacity (practical – Abril et al. or operational capacity – Transnet) is the most significant measure of railway capacity as it considers the combination of traffic, infrastructure and operations within an expected service level (49). Operational capacity = theoretical capacity − [operational and maintenance allowances]

2.3.5 Overview of contributing elements to capacity

Capacity is a complex issue that is created or destroyed by a multitude of interrelated factors that are (49). These factors are:

- **Service Design** – the train service design comprises the selection and scheduling of services, specification of terminal operations and routing of freight (62). Train service design

[5] i.e. operational capacity is not the capacity that is available at the time of use due to the condition of the line as may be inferred purely from the denotation of the term 'operational'.

has a direct impact on capacity as it outlines the design of the delivery of the transportation service in line with stakeholder expectations (63). Figure 13 illustrates the relationships within the service design activity.

- **Rolling stock** – the locomotives, electrical units, railway vehicles and shipping containers that carriage and transport the freight is a major contributor to capacity (64). In addition, the length, speed and diversity of the trains available and operating during a service directly impacts capacity (65)
- **Signalling** – signalling is crucial to capacity since it directs the way in which train movements are controlled and affects the safety of cargo, train crew and rolling stock. Operations of the railway system are directly affected by the operational (manual or automatic), functional (purpose of signal) and locational characteristics of the signalling system (66)
- **Terminals** – terminals can serve a shunting or intermediary function. Terminals, which are often commodity-specific, can have an impact on capacity as they directly impact traffic management and accessibility of the service (67)
- **Track infrastructure** – the ownership of track infrastructure, track layout (single or double), distance between sidings, length of siding and condition and grade of the track have a significant impact on the capacity of the railway network (65)
- **Crew** – the crew needs to be scheduled, just as with the non-human aspects of the railway system. Developing an operating plan that is both feasible and connects with the other schedules of the network is a challenge. Crew capacity is a factor of overall railway capacity (68)

2.3.6 Maintenance and operational allowances

This section gives an overview of considerations for operational and maintenance allowances that have a direct consequence on operational capacity.

2.3.6.1 Operational allowances

In order to avoid disturbances propagating, allowances in the form of slots are added to the technical minimal running or dwell times during timetabling (69). Increasing the size of the allowances increases the reliability of the timetable by acting as a buffer but also increases the travel time – an important timetable quality criterion (70). The challenge with timetable construction is to find an optimum between achieving short travel times, increasing capacity and enabling smooth and safe operation (71). In order to optimise recovery times, it is essential to know the different types of disruptions (72).

In 2018, a focus group was conducted with Transnet operations subject matter experts to understand Transnet’s freight transportation operational challenges as part of an operations centre development project. Mind maps capturing the full set of result of these focus groups are contained in Section

4.1.1. The focus group determined the main factors contributing to staged, cancelled and delayed trains to be:

- **Customer-related factors** including cancellations, loading and offloading equipment failure and lack of product availability
- **Crew-related factors** including absence of an available crew, crews not being booked or a crew shortage
- **Environmental and social factors** including adverse weather conditions, labour unrest and community unrest
- **Operations factors** including late shunting, communication breakdown and unscheduled trains being added to the track
- **Safety factors** including incidents, theft, derailments and accidents
- **Technical factors** including locomotive failure, unplanned occupations and rail network maintenance

The contribution of operations-related issues to delayed trains was estimated to be about 50% of total contributions and the contribution of technical operations was assumed to be 30%. Figure 11 contains a pie chart representing an example of relative contributors to delayed trains with the assumption that the crew, environmental and social, customer and safety related issues each contribute 5% towards the total contributions.

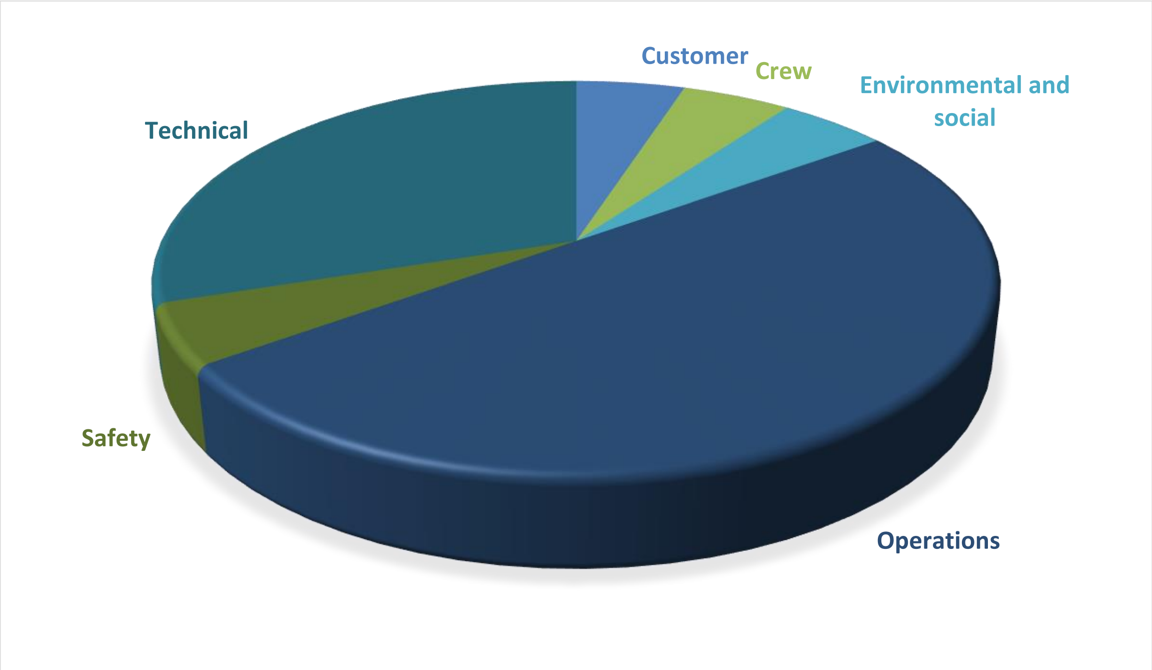


Figure 11: Contribution of operational challenges from the six main factors for delayed trains

The magnitude of contribution of each of these factors to staged, cancelled and delayed trains varies depending on a range of criteria. One of the most significant criteria is the cargo being transported via that corridor and characteristics associated with transporting each of the different types of cargo (18). To this end, Transnet operates business units dedicated to transporting different cargo, namely (73):

- Agriculture and bulk liquids
- Containers and automotive
- Coal
- International business
- Iron ore and manganese
- Mineral and chrome
- Steel and cement

Various types of cargo will differ depending on the warehousing and preparation for further transportation, customs formalities, loading mechanisms, departure locations and associated destinations and routes (74).

In addition, the Roberts et al. interview with experts in freight rail transportation in 2010 revealed the following operational challenges as risks to reaching anticipated capacity levels:

- a lack of a strategy
- clashes between interfacing organizations
- conflicts from various operators on the same line*
- misalignment between the concept of operation and the demand from the market
- a lack of synergy between planning activity and operational activity
- the policy of compiling crews
- poor understanding of the differences between passenger and freight requirements

All of the above challenges may have a negative impact on capacity. The above operational challenges, with exception of *conflicts from various operators on the same line should all be addressed through strategic planning and implementation and thus should not have an influence on operational capacity (20). That is, allowances should not be granted for potential clashes between interfacing organizations as these matters should be resolved with the relevant stakeholders reflected in Figure 10, at the business level.

2.3.6.2 Maintenance allowances

Transnet recognises the following service categories for on-track maintenance (75):

- Ballast tamping services
- Sleeper replacement services
- Rail grinding services
- Drain cleaning services

- Universal sleeper replacement services
- Turnout replacement services
- Ballast screening services
- Ultrasonic measuring car services
- OHTE services
- Sleeper recycling services

Assigning allowances for maintenance involves assigning slots to perform these various types of maintenance activities (75). The degree of allowance allocated depends on a multitude of factors which are outlined below:

1. **Material interaction between infrastructure and trains**
   There is a strong relationship between the infrastructure/train interface and the amount of maintenance to be conducted. Specifically, the requirements tolerances for load bearing and rail surface quality will vary for different combinations of materials and will all have an impact on the degradation speed for both trains and track (70). This influences the frequency of train wheel and track maintenance activity.
2. **Interdependence between system elements**
   Various subsystems will interface with a different proportion of the network or have varying impacts on overall network operations during maintenance due to the logical or physical structure. Maintenance frequency and effort will be different for each of these subsystems. For example, signalling interlocking systems will have significant impacts on the network and thus maintenance is likely to performed infrequently and with careful planning (76).
3. **Safety**

   Safety is crucial when performing maintenance – safety for the workforce as well as the assets. Improving safety typically means an increase in maintenance time and hence its allowance (72) (70).

4. **Organization and regulation**
   Where functional units such as design, construction, planning, procurement or maintenance are geographically or organisationally distributed, there will typically be a necessity for maintenance contractors which requires longer lead times for planning (72). Rules and regulations are usually a large contributor to whether maintenance work can be carried out for example rules regarding allowed maintenance on parallel track if the traffic obeys the limit (e.g. Sweden) or not at all (e.g. Holland) (70).

Other notable considerations when allotting for allowances include (70) (77):

- what the actual maintenance activities are
- what the preconditions and effects of the tasks are
- what equipment and which crews are involved

- what duration of time possession is required and what duration of time is granted
- what degree of coordination is required
- what the associated costs are, which may influence capacity directly or indirectly
- how the maintenance varies with seasons

Peng and Zhang et al. state that maintenance can be categorised according to the following considerations (77) (72):

1. **Proactive or reactive** (i.e. maintenance in anticipation or after incident, respectively)
2. **Capacity usage** (i.e. segmenting by the impact of the maintenance on the network)
3. **Planning horizon** (this is affected by the degree of organisational effort required to coordinate efforts/the frequency that maintenance is required for various elements)

These are decisions that will influence the amount of maintenance allowance afforded in capacity planning.

2.3.7 Capacity planning

The challenge of evaluating route capacity exists because the railway network has several relevant parties to be considered in construction, maintenance and operation. There is a combination of civil, mechanical, environmental and electrical engineering and a diverse range of organisations involved in control and management (78). This requires substantial planning to coordinate (20). Planning is a management activity which supports decision-making and improves the performance of the railway system (78).

Capacity planning is defined as the process of consolidating all capacity needs for each period (short, medium and long term) and determining the best way to meet the need (59). Bangladesh Open University, Pouryousef and CDC, define the following stages as part of capacity planning shown in Figure 12 (59) (79) (80):

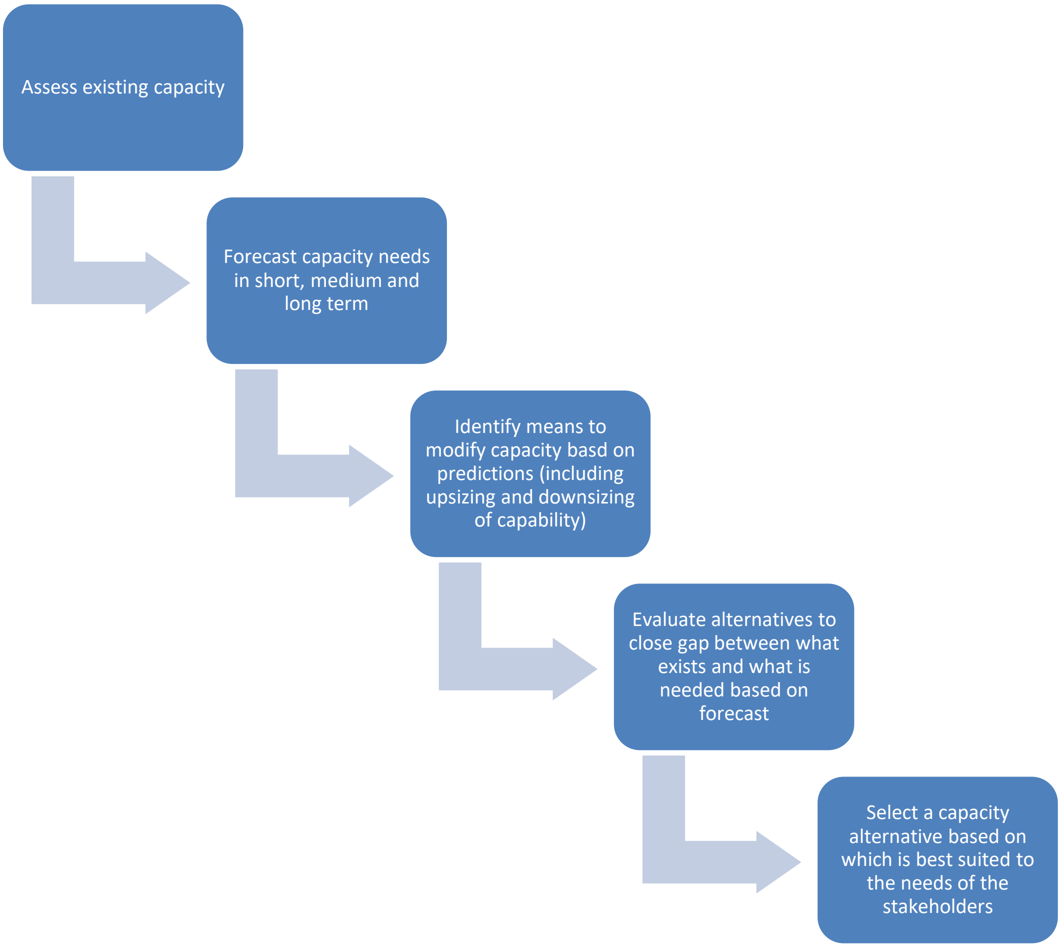


Figure 12: Steps in capacity planning

(Adapted from (79) (80))

Capacity planning can be characterised according to time schedules (78) (9):

- Strategic planning (long-term planning) involves company and process development. This includes allocation of resources to capital and asset investments.
- Tactical (medium-term planning) involves development of timetables and analysis pf congestion and performance. Options for meeting the demand when infrastructure and assets are fixed is commonly presented through alternative train schedules (16).
- Operational (short-term planning) involves execution on the same day of service delivery

2.3.7.1 Capacity planning and scheduled railways

As highlighted in Section 2.3.1, one of the most commonly referenced capacity definitions relates capacity to the 'the highest volume that can be moved over a subdivision **under a specified schedule and operating plan'** (Krueger, 1999). A major consideration in capacity planning is whether or not to use a scheduled approach. Scheduling describes the time allocation of resources to meet demands in completing a task (81). Transnet Freight Rail transitioned from tonnage-based dispatching to scheduled railway operation in 2011 (82). Transnet made the decision to transition to scheduled operations in an effort to reduce operating costs, increase capacity, improve asset utilization and improve coordination and reliability of railway operations (83). The tonnage-based system relies on minimising the total number of trains and maximizing the length of trains but it ‘disrupts efficient utilization of crews, locomotives and equipment’, says Transnet spokesperson Sandile Simelane (82).

2.3.7.2 Freight rail operations and scheduling

Train service design addresses the planning of various railway operations by allocating resources to activities that will meet the stakeholder objectives of the railway system. Several decisions are related in service planning (84) (85) (86):

1. **Service selection and scheduling**

The service selection and rescheduling decision-making activity pertains to coordinating train route and train type. A train route has an origin, destination and sequence of yards that are visited along the way and the train type relates to the planned speed, capacity and priority of the train (84). Scheduling involves assigning train types along train routes and is performed for a predetermined period of time and is repeated for a certain period (planning horizon). A timetable contains arrival and departure times for each yard on the route.

2. **Car classification and blocking**

Cars classification and blocking decision-making activity groups cars together to form a block which are then transported to yards to be assembled into trains.

3. **Train make up**

The train make up decision-making activity states the blocks that a train will haul from origin to destination and the blocks it may pick up at the intermediate stops.

4. **Freight routing**

The freight routing decision-making activity determines the itinerary for the transportation of blocks, trains and the corresponding yard operations. This is based on the demand of the customer and the required positioning for empty cars.

The selection of services, blocks, schedules and routes have network-wide impacts and have a complex relationship to economic, time and space dimensions. Service design is thus a complex, multidimensional activity (87). The relationships between various service design elements are illustrated in Figure 13. For the illustration of these relationships, a component relationship diagram was used to extract themes out of the complex elements at play in operations of a freight railway network. This representation was chosen over a functional diagram such as an Entity Functional Flow Block Diagram (EFFBD) or Activity Diagram used in Systems Modeling Language (SysML) in which the purpose of those diagrams is to extract errors in analysis, capture requirements or determine design aspects related to system behaviour, as described by Project Performance International (26). The emphasis in Figure 13 is on theme extraction rather than behavioural analysis.

Although there are many aspects associated with service design, Canca et al. state that timetables represent the step with most influence on user's perception about quality of the service and thus timetables are a good reference point for capacity evaluation (88).

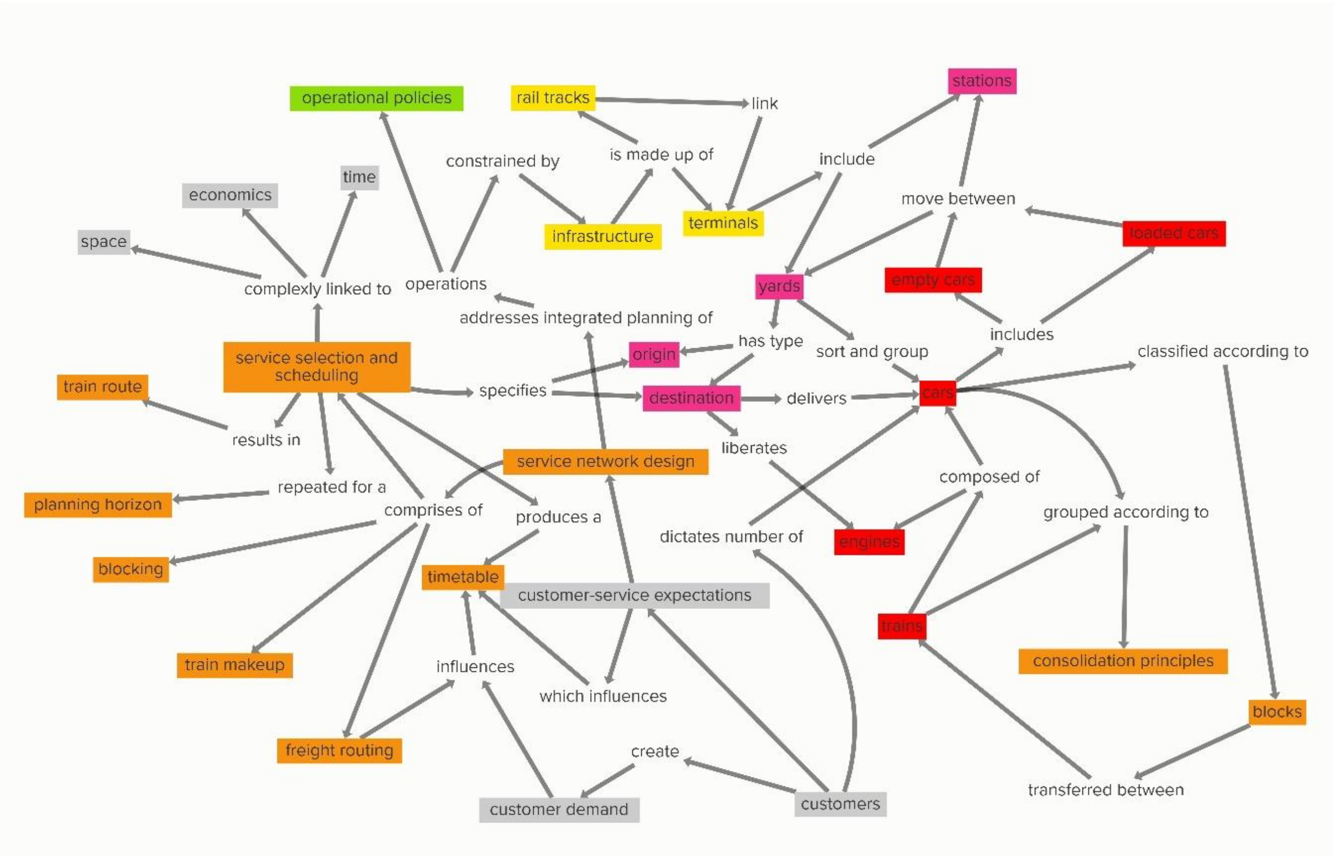


Figure 13: A relationship diagram illustrating the overall operations of the freight railway network from a scheduling perspective

(86) (84) (85) (85)

In freight railway, the operation model and indeed, timetable is impacted by demand for services, production patterns, traffic rules and priorities. Demand influences the origins and destinations and production patterns influence the operating forms (78)

2.4 Timetabling

Timetabling is the process of planning a schedule that is feasible for every train path and includes sufficient separation between trains and adequate allocation of crew members and rolling stock (89). During operation, train rescheduling takes place in order to restore operations when disruptions to timetable execution occur as a result of issues such as accidents or technical problems (90). This is an operational planning decision.

2.4.1.1 The significance of timetables in railway capacity

Brebbia et al. state that 'timetable analysis has proven to be efficient for capacity evaluation' (76) . This is supported by the following statements from literature:

- Avelino, te Brömmelstroet, & Huister state that there is a close interaction between infrastructure, achieved capacity and timetable planning (2006)
- Landex, et al. affirm that capacity achieved is directly related to implementation of constructed timetables i.e. capacity may be viewed as the capability of an infrastructure system to handle one or more timetables (2011)
- Michal, et al. state that a candidate timetable describes operating patterns and infrastructure occupancy therefore evaluating a timetable results in an evaluation of the infrastructure utilisation as well as the pattern of operation (2016)
- Predictability of capacity is closely related to how adequately and accurately the train timetable performs (91)
- UIC, Pachl and Hansen note that improving the timetable is the best way to increase capacity (UIC, 2004), (Pachl, 2004) (Hansen)

Poister declares that timetable evaluation should produce objective, quantitative information about the expected operational performance of the railway network *from the viewpoint of the stakeholders* in order to support management in decision making and performance improvement (2008). That is, the timetable is evaluated from the perspective of the various stakeholders including infrastructure owners, organizations concerned with sustainability and society, regulatory bodies, standards bodies, customers and operational departments as depicted in Figure 10 in Section 1. The relationship between the infrastructure planning, construction, operation and maintenance process and the timetabling planning process is visualized by Canca et al. (2014) in Figure 14.

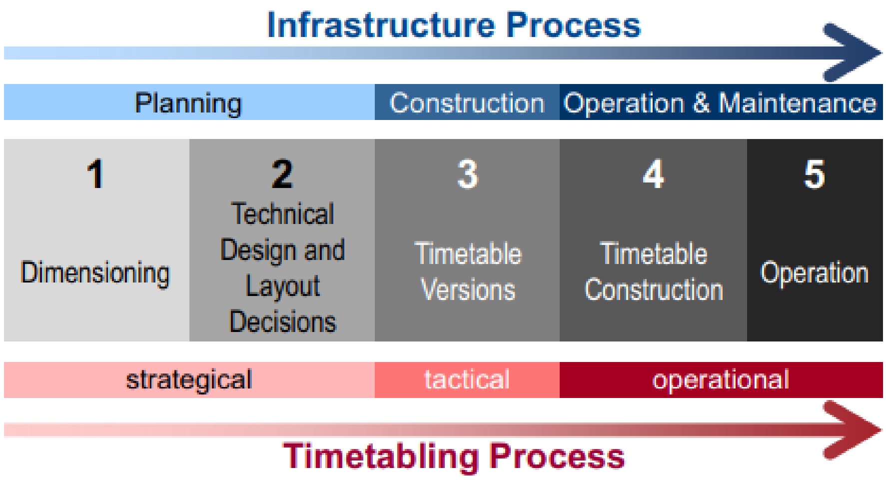


Figure 14: Timeline diagram for infrastructure and timetabling processes

Adopted from Canca et al. (2014)

2.5 Timetable Evaluation Metrics

The challenge with evaluating a timetable is establishing the set of metrics for evaluation in light of varying perspectives from the set of stakeholders (89). A critical review of the literature revealed several timetable evaluation metrics identified in several areas of interest. The results of this review are contained in Table 5. Metrics have been grouped according to interest area and stakeholder with a vested interest in that area of interest, from the set of stakeholders in the transportation sector highlighted by Cloete-Hopkins (see Figure 10). The primary stakeholder and secondary stakeholder in any project is 1) the (profit-seeking) company itself and then 2) the customer (26). Other stakeholders not directly related to providing the business or creating a demand for the business are tertiary stakeholders but they still contribute requirements to the business (26). The timetable evaluation metrics have been organised according to this standard of prioritization of stakeholders.

Table 5: Timetable evaluation criteria

Interest area w/ stakeholder	Timetable evaluation metric	References(s)
Efficient use of infrastructure ***Stakeholder perspective:*** ***Strategic (Infra Owners)***	Scheduled waiting time	(92)
Economics ***Stakeholder perspective:*** ***Strategic (Infra Owners)***	Operating expenses	(86) (93)
	Operating revenue	(86)
	Percentage of market share	(86)
Timetable generation timing, scalability and flexibility ***Stakeholder perspective:*** ***Operational – Transport/Logistics***	Timeliness of timetable preparation	(92)
	Flexibility of train driver change over	(92)
	Scalability of timetable	(92)
	Coordinated with international timetable slots	(92)

Maintenance and Preservation ***Stakeholder perspective:*** ***Operational Transport/Logistics***	Maintenance cost per track kilometre	(94)
	Number of train disruptions due to infrastructure	(94)
Level of service (indicator of customer satisfaction) ***Stakeholder perspective:*** ***Customers/Programme***	Percentage of primary delays	(57)
	Percentage of secondary delays	(16)
	Freight delivery metric (FDM) – percentage of freight trains that arrive within 15 minutes of scheduled time	(57) (16) (89)
Robustness of timetable ***Stakeholder perspective:*** ***Customers/Programme***	Reserve freight train timetable slots	(92)
Mobility, reliability and congestion ***Stakeholder perspective:*** ***Customers/Programme***	Tons or ton-miles of freight over relevant period	(95)
	Average terminal dwell time (train-hours of delay)	(95)
Accessibility and connectivity	Percentage of shippers within 50 mile-radius of	(95)

Stakeholder perspective: Customers/Programme	intermodal trailer-on-freight-car (TOFC) facility	
	Service coverage	(93)
	Just-in-time delivery	(96)
	Convenience during acceptance and issuance of goods	(96)
	Avoidance of intermediate transhipment operations	(96)
	Presence of additional services	(96)
	Access to reliable information about rates, conditions of carriage and location of cargo	(96)
Safety ***Stakeholder perspective: Governance and Technical***	Total loss and damage from accidents per route-mile	(95) (93)
	Total loss and damage from accidents per tonne moved	(95) (93)
	Train derailments per tonne moved	(95) (93)
Environmental ***Stakeholder perspective: System/Society/Sustainability***	Pounds of greenhouse gas emissions	(95)

The above set of metrics are useful in evaluating a timetable, which in turn evaluates the level of capacity from the stakeholders' perspective (97) (76) (91).

2.6 Systems Engineering Approaches to Evaluation

PPI defines the systems engineering process element, 'effectiveness evaluation and decision' as the activity in which the most effective feasible (design) alternative is selected on the basis of a set of inputs, thus producing a set of outputs (26). The inputs to the effectiveness evaluation and decision activity are (26) (98):

- Design alternatives that all meet the requirements (imperatives)
- Data for characterization of feasible design alternatives plus uncertainty information, if available
- Evaluation model upon which the selection (and even optimisation) of a solution alternative will be made.

Outputs to the process element include:

- The design decision
- Rationale that supports the design decision

The next sections will describe tools used in the process of evaluation, mostly by systems engineering and project management practitioners.

2.6.1 The value model

Ryschkewitsch et al. describes systems engineering systems engineering as an art and a science where, like in an orchestra, multiple participants are brought together with different levels of skills and different expertise to produce something greater than its parts (i.e. a system or a piece of music) (99). In essence, it involves adequately defining a problem and then using knowledge and creativity to develop a solution that meets that problem (27). One major output of problem definition is a requirement specification – a document that stipulates all that is necessary to be done, made or provided (101). A solution to a problem is adequate if it meets the requirements but requirements are only useful insofar as they capture the need of the stakeholders (100). A requirements analysis process that outputs this specification typically occurs during the 'concept' phase of the system life cycle as illustrated in Figure 8 in Section 2.2.2.

Requirements capture the imperatives that are to be met through a solution however sometimes solution A is perceived as better than solution B as a result of higher perceived value by stakeholders. For example, in the development of a transportation solution where the objective is to get from starting point X to end point Y in a M about of time. If solution A allows for this to be done at a lower cost and with less negative impact on the environment, it may be preferable over solution B even though both solutions meet the speed requirements. Systems engineering provides a structured approach to selecting between viable alternatives (26). One way of doing so is through the application of the value model.

2.6.1.1 *Description of the value model*

Figure 15 presents an example of a value model which is comprised of a system effectiveness component (left) and the application of the system effectiveness model to a potential solution (right). The system effectiveness model contains a set of measures of effectiveness [MOEs] (value adding criteria beyond the requirements), with worst and best values, priorities, weights and utility functions. This is the set of data against which design alternatives will be assessed in order to decide which solution is best or the set of data against which a design is optimised in order to optimise a solution. Each of the columns and their purposes will be described in the subsequent paragraphs. The descriptions were obtained from Project Performance International (2017).

MOEs	Worst	Best	Pri.	Pts	Weight %	UF	Value of MOE	RVC	AVC (RVC x wt)
Rail-Road Safety, APAs	1	0	2	80	24		6	4	96
Investment Cost, $k-RC	250k	150k	6	20	6		170	10	60
O,S Cost, $k/20yrs-RC	250k	100k	4	40	12		220	1	12
Investment Cost, $k-RTA	20k	5k	9	1	0		—	—	—
O&S Cost, $k/20yrs-RTA	20k	5k	8	1	0		—	—	—
Reduction from track speed %	50	0	3	60	18		25	9	162
Reduction from road speed %	50	0	7	10	3		40	3	9
Availability, %	.99	1	5	20	6		.995	5	35
Fail-Safe Reliability, 0-1	.9999	1	1	100	30		.99995	5	150
Aesthetic Appeal, SAAI 1-10	1	10	10	1	0		—	—	—
				Σ 333	100				Σ 524

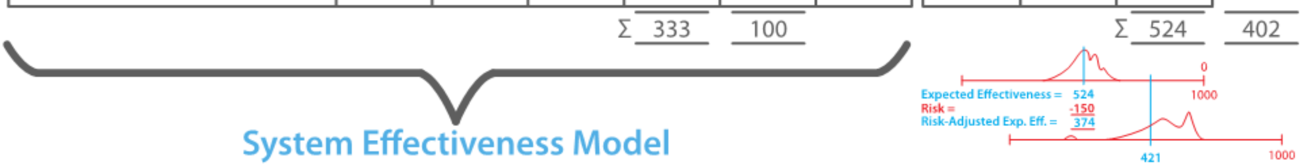


Figure 15: Value model for a railway crossing

(Adopted from (26))

Expansion of abbreviated terms in the value model (in order of appearance)

APA	Railway company internal definition and scale of railway safety factors
RC	Railway Company
O, S Cost	Operational and Support Cost
RTA	Rail Traffic Authority
SAAI	Railway company internal definition and scale of aesthetic appeal

Measures of Effectiveness

An outcome valued by the stakeholders where improvement beyond the requirements will lead to high levels of satisfaction by stakeholders.

Worst

The value of the outcome that is just about acceptable (often it is the value of the requirement).

Best

The value of the outcome that represents the threshold of potential feasibility, given the constraints by technologies and other requirements.

Priority

Represents relative value of improvement from Worst to Best i.e. if all MOEs were at their best and the stakeholder is offered to improve one, which would he/she choose? This question is repeated for the second priority measure and is continued all the way through until all the MOEs have been assigned priorities.

Points

Priority of improvement from Worst to Best expressed as a value from 0 to 100 where 100 is assigned the highest-valued measure.

Weight

The values in the Points column as a percentage of the sum of the column.

Utility Function

A graphical representation of the change in relative value, as the value of the MOE varies from Worst to Best. The Worst value corresponds to 0 and Y axis and the Best value corresponds to 10. Whatever value is expected to be achieved by the solution in question is assigned a value from 1 to 10 depending on which number it corresponds to on the basis of the graph (see below).

Value of MOE

The predicted outcome for each of the MOEs for the solution alternative under consideration. In Figure 15 above, the density function shows the probability density function (PDF) over the Worst to Best range to capture uncertainty in the value of the MOE. For example, for investment cost value, the solution in question is expected to cost $170 000 per rail crossing with some degree assigned to that estimate.

Relative Value Contribution (RVC)

This is the value of the utility corresponding to the predicted outcome for each MOE, as determined by the Utility Function. For example, for an investment cost of $170 000 per rail crossing, when moving horizontally from the X-axis from the point of $170 000 on the scale, the graph is met at Y =

4. Thus, the relative value contribution is 10 and there is range of uncertainty associated with this value as a result of the uncertainty of the value of the MOE. This is shown through the PDF over the value of 10.

Absolutely Value Contribution (AVC)

Absolute Value Contribution multiplies the weight of the MOE by its RVC. The multiplication results in a simple scale change. For example, for the investment cost, an RVC of 10 was obtained and the relative weighting is 6 %. Thus 10 x 6 = 60 which is the value of the AVC, again with uncertainty depicted through the PDF.

The Overall Effectiveness is the arithmetic total of the AVC which may be obtained by Monte Carlo simulation or otherwise if there is uncertainty in the values.

2.6.1.2 Strengths of the value model (author's analysis)

The strength of the value model is that it allows attributes with different units to be brought together for evaluation of a design/solution in a holistic manner. The value model captures the notion that perceived value changes over a tradeable range (26). As was described by the Utility Function for investment cost in example above, an investment cost in the range of \$150 000 to about \$190 000 still receives a 10/10 in terms of value satisfaction by stakeholders however as cost exceeds \$190 000, this value impression drops drastically where at a cost of \$ 200 000, the value impression is close to 3/10. This is the nature of many value-adding attributes of a solution and the value model allows for exactly this to be captured.

Another strength of the value model is that it captures the separation of priorities through the assignment of Points and Weights. For example, simply listing value measures from 1 to 10 implies that there is an even distribution of drop in value perception from 1 to 10 which is not true in many cases. For example, in the above value model, the 10 priorities have the following weights associated with them (see Table 6):

Table 6: Example priority, points and weight (%) of crossing MOEs

MOEs	Priority	Points	Weight (%)
Fail-Safe Reliability	1	100	30
Rail-Road Safety	2	80	24
Reduction from track speed	3	60	18
O, S Cost - RC	4	40	12
Availability	5	20	6

Reduction from track speed	6	20	3
Reduction from road speed	7	10	3
O, S Cost – RTA	8	1	0
Investment Cost	9	1	0
Aesthetic Appeal	10	1	0

There is a linear perception of value change from Priority 1 to Priority 5 as these are each separated by 6% whereas there is a gentler roll of value perception from Priority 6 to Priority 7 after which the MOEs have virtually no relative value. The Points and Weights in the above example were established through a 'quick and dirty' approach i.e. by postulating the relative scores. For high risk scenarios, a more sophisticated method of establishing priorities, the Analytic Hierarchy Process (AHP) may be used (102).

2.6.1.3 Limitations of the value model (author's analysis)

The limitation of the value model is that it does not provide insight into relationships between the various measures i.e. if the value of one attribute is increased, this may be coupled to another value which may lead to a decrease of another value and therefore a change in the overall contribution of a feasible solution.

A second limitation is that this method of evaluation is well-suited to concepts where there is a simple relationship between the proposed solution and the values perceived by the stakeholder i.e. it is simple for 'black box' solutions. If there is a more complex relationship that exists between each of the contributors to operational capacities and the overall stakeholder value perception i.e. if there is a relationship between the internal components of a solution and each of the measures of value perception, a white-box evaluation method may be preferred. The contributors to operational capacity (or risk factors that necessitate allowances to be applied) were discussed in further detail in Section 2.3.4). This is because, for each line or network, there is a different degree of risk associated with what cargo is carried, what the state of the infrastructure is, who the customers are, what degree of maintenance is regulated, the difficulty of the maintenance activities to be performed and so forth thus allowances applied to mitigate the risk will vary depending on the operating and maintenance conditions that prevail. The value model does not allow for relationships between internal solution aspects and the impact on stakeholder perception to be captured.

2.6.2 Quality Function Deployment

2.6.2.1 Description of QFD

Quality Function Deployment (QFD) is a coherent methodology to translate customer demands into actionable techniques in order to deliver maximum value to customers (103). QFD was selected over other numerical methods such as analytical network process (ANP) due to its seamless integration of multiple stakeholders through the ‘voice of the customer’ approach as stated by Hosseini et al. (104). QFD also has the advantage of providing a clear visualization of the components of the system under analysis which is valuable in communicating with stakeholders from different backgrounds. In addition, QFD has an advantage over the Kano Model approach in that it captures the input of stakeholders beyond the customer and is much quicker in its implementation than is the Kano model as described by Tontini (105). The most abundant application areas of QFD include product design, logistic management, shipping investment and countless others (20).

The core of QFD is the House of Quality (HoQ) shown in Figure 16. Not all of these components (A – G) are used in all HoQs. The voice of the customer (Demand Qualities) are shown on the left, these are the attributes of greatest concern to the customer. The controlled factors (Quality Attributes) leading to achievement of the VOC factors are shown across the roof of the house. The matrices capture relationships between the demand qualities (A), the quality attributes (E) and between the DQs and QAs (F). The importance of each of the qualities is highlighted in the HoQ, too.

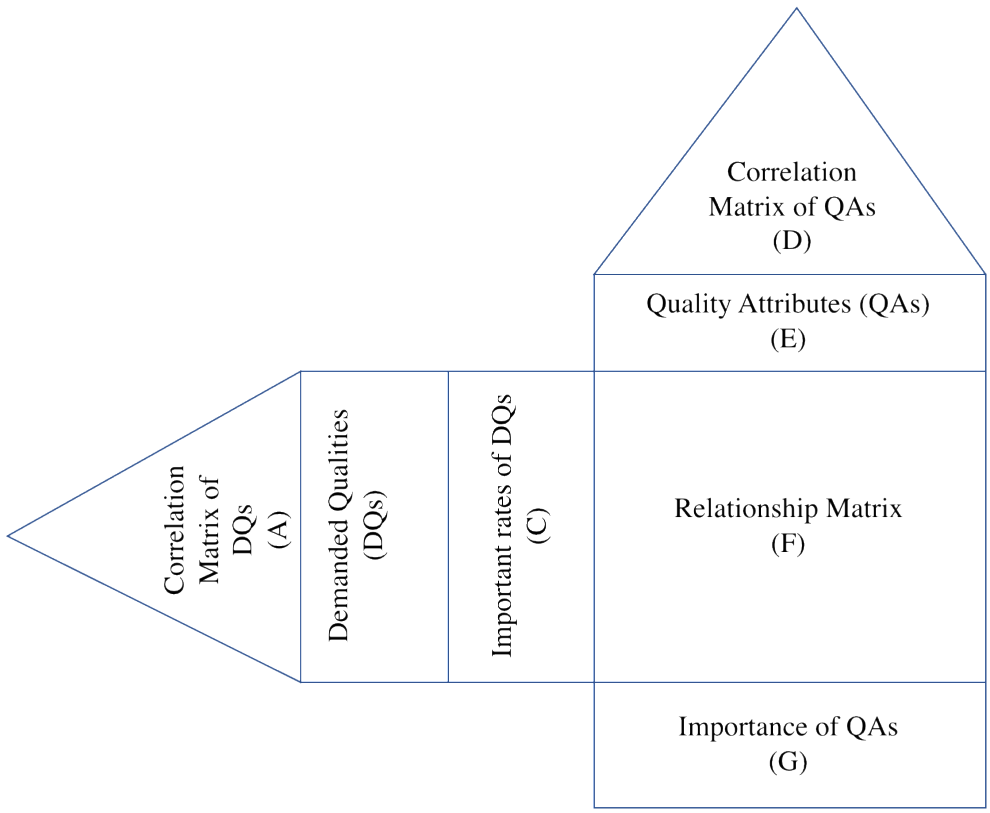


Figure 16: Basic structure of the House of Quality (HoQ)

(Adapted from (103))

Multiple versions of the HoQ exist, each adapted to various needs. Figure 17 captures an example HoQ for a drone design for a drone manufacturing company, FlyCo. It also contains the use of the comparative assessment on the far right which compares the FlyCo drone to the drones of four other competitors. The assessment of a specific company with other competitors is common in HoQ analyses (20).

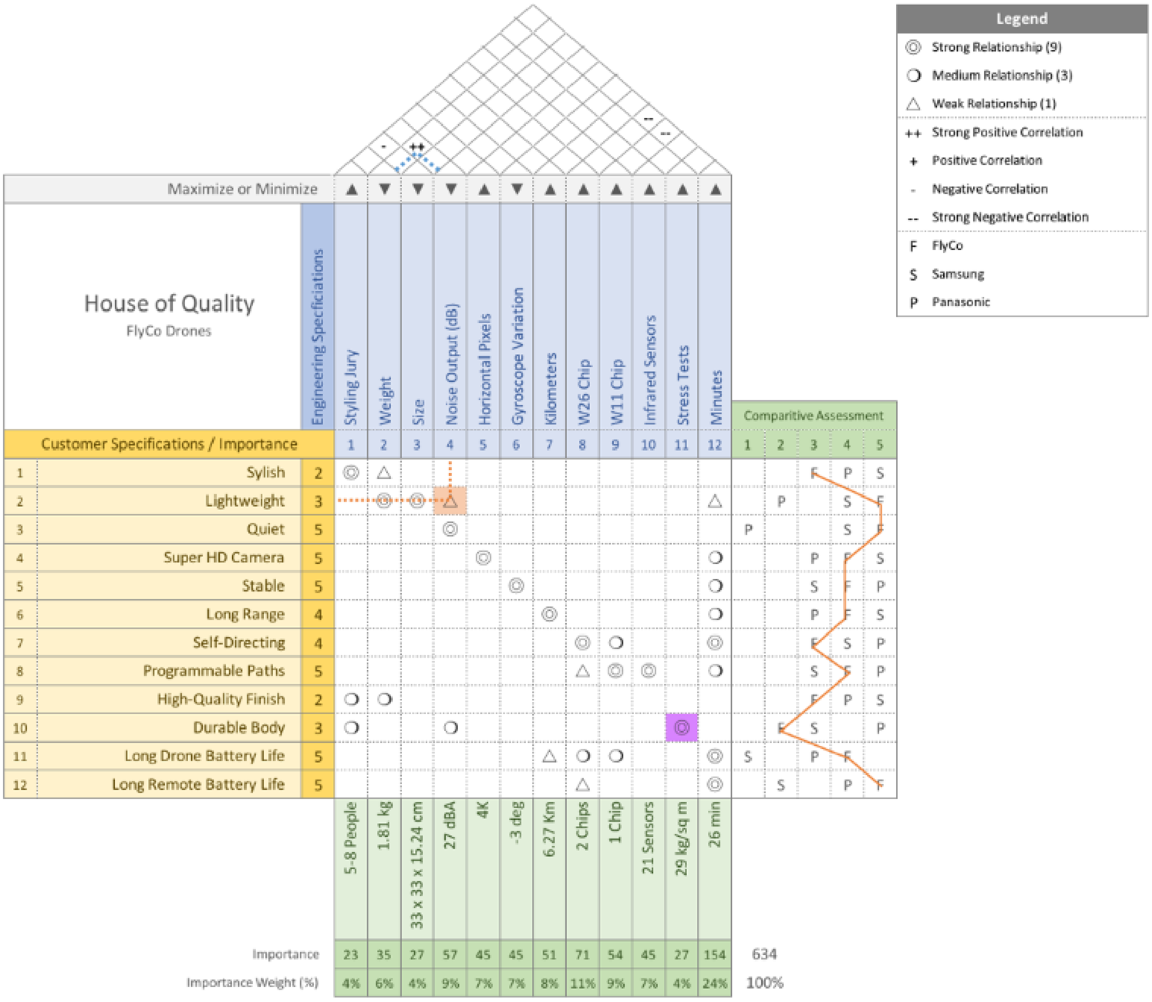


Figure 17: Example HoQ for a FlyCo drone

(Adopted from (106))

An HoQ like the one above will usually be compiled in a multidisciplinary group which can provide input as to the nature of the relationships between the voice of customer needs (DQs) and the controlled factors (QAs). The Quality Attributes (QAs or controlled factors) are variables that are manipulated in order to achieve the Demand Qualities (DQs or customer needs) (103). In the example above, the strength of the relationship between the customer needs and the controlled factors is captured in the central matrix. Importance for the customer needs have been established by allocating a priority from 1 to 5 where multiple criteria can have the same importance level. The importance of the controlled factors is determined by finding an estimate of the extent of impact of the controlled factor (QAs) on the customer need (DQs). This is achieved by summing the values, for each controlled factor, of the symbols that capture the estimated strength of relationships between the relevant control and each of the customer needs. The legend in Figure 17 outlines the meaning of each of the symbols.

2.6.2.2 Strengths of the HoQ (author's analysis)

The greatest strength of the HoQ is that it picks up on relationships in a number of directions. First and foremost, it highlights the relationships between the customer needs and the controlled factors. Secondly, there is provision to extend the HoQ to the 'roof' of the house to highlight relationships between the controlled factors, or to extend the HoQ further by rotating the roof 90º anticlockwise to highlight the relationships between the various customer needs. Highlighting relationships between multiple elements is the greatest value derived from the HoQ.

2.6.2.3 Limitations of the HoQ (author's analysis)

A major limitation of the HoQ is that most of the measurements of competitor products are assigned on the basis of contributing a score from 1 to 5 for various attributes but this may not create sufficient separation between objects of measurement. In addition, there is currently no provision in the framework to prioritize customer needs with greater separation through postulation, AHP or otherwise. Lastly, the HoQ provides no means to understand the change of customer-perceived value over an acceptable range of values of each of the needs.

3 RESEARCH METHODOLOGY

The research methodology followed in any research project is of primordial importance because it affects the results – an unreliable method produces unreliable results which undermines the value of the various findings and their consequent analysis (107). This section outlines the research approach and that was adopted in order to synthesize and validate the conceptual framework that is the main artefact of this research undertaking.

3.1 Research Design

The research onion developed by Saunders et al outlines stages through which a researcher must pass in developing an effective methodology (108). The 'layers' of the onion represent methodological decisions to be made by the researcher. The research onion as applied to this research project is presented below with the decisions taken for each of the layers circled accordingly.

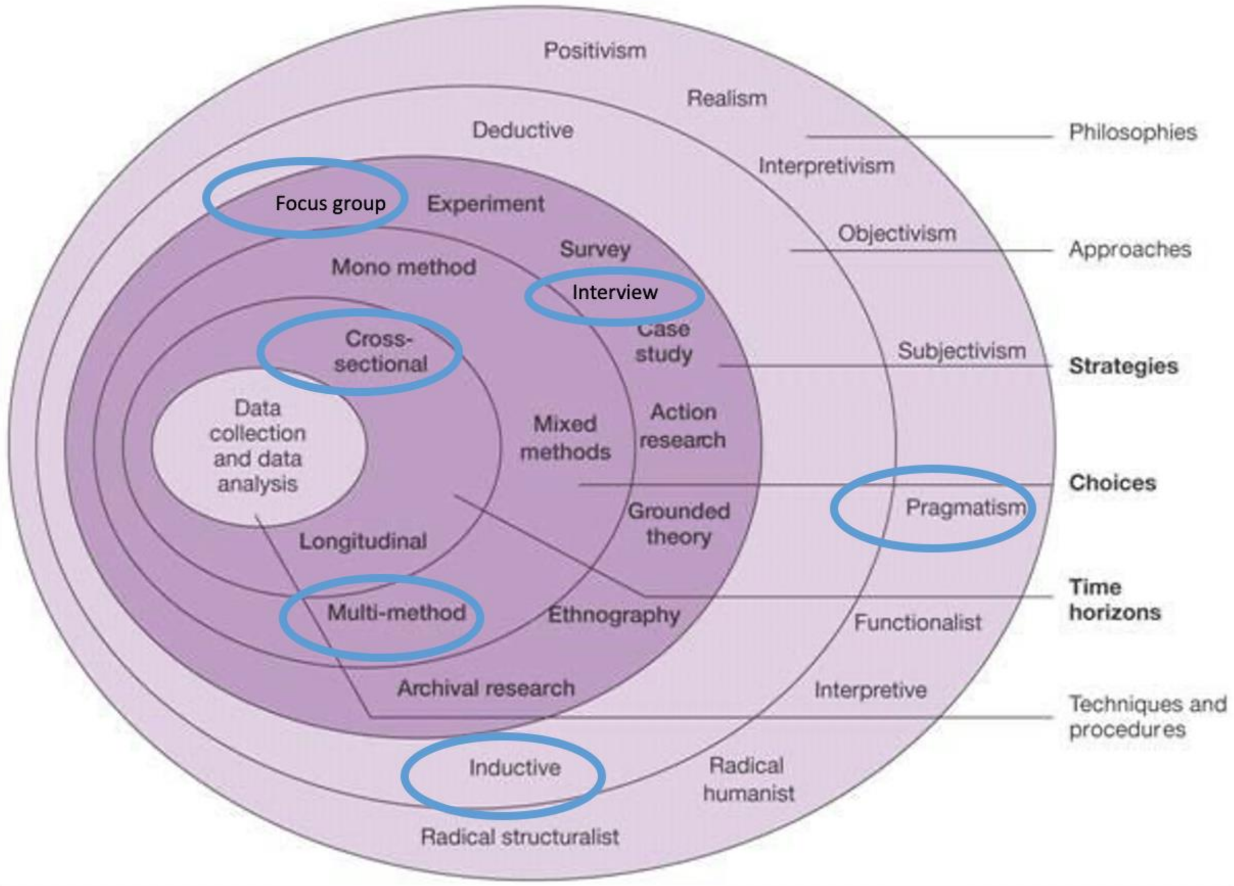


Figure 18: Research Onion developed by Saunders et al. applied to this research project (109)

This section will provide an explanation for each decision taken:

- Pragmatism was selected as the research philosophy because a solution to the problem of understanding and evaluating operational capacity was identified through the application of theories and frameworks
- Inductive research was chosen as the research approach as the research necessarily starts from general concepts and proceeds to lower levels of detail as the research develops
- A focus group was selected as the initial research strategy in order to collect a large amount of data thereafter interviews were carried out in order to dive into greater detail
- A multi-method research choice was selected due to the qualitative collection of data and qualitative and quantitative processing of data in formulating the framework
- A cross-sectional time horizon was appropriate as the time for the research to be conducted was pre-determined and was not dependent on time-varying factors

The research onion provides clarity on research design choices. The next section describes the research design that was adopted to ensure reliable and valid results.

Joppe states that for *quantitative* studies reliability is the extent to which results are consistent over time and validity is in an indication of how truthful the results are (110). Seale states that for *qualitative* research trustworthiness is the intersection of reliability and validity for *qualitative* research (111)Patton and Mathison encourage triangulation as a means for demonstrating trustworthiness in *qualitative* research as it controls biases and establishes valid propositions (112) (113) (. Johnson stipulates that open-ended data triangulation allows participants to assist in refining the problem definition as well as with collecting data (114)

Triangulation uses multiple methods or data sources in order develop richer understanding. Triangulation tests validity through convergence of information from different sources The oobjective of triangulation is to increase confidence in findings through confirmation of proposition using two or more methods or sources. B2B Whiteboard highlight the following the following are advantages and disadvantages to using triangulation (115):

<u>Advantages:</u>

- leads to unique findings
- provides confidence in results

<u>Disadvantage:</u>

- can be time-consuming
- can be challenging to resolve disharmony
- assumes one truth to be applicable and achievable

To achieve triangulation, a sequential multi-method approach was used. The steps followed can be described as shown in the flow chart below. Steps 1 and Steps 3 will be discussed in the following paragraphs, Step 2 will be covered in Section 3.3 of this section. The other Steps are covered in different parts of this research report as highlighted in the blocks to the right of the flow chart.

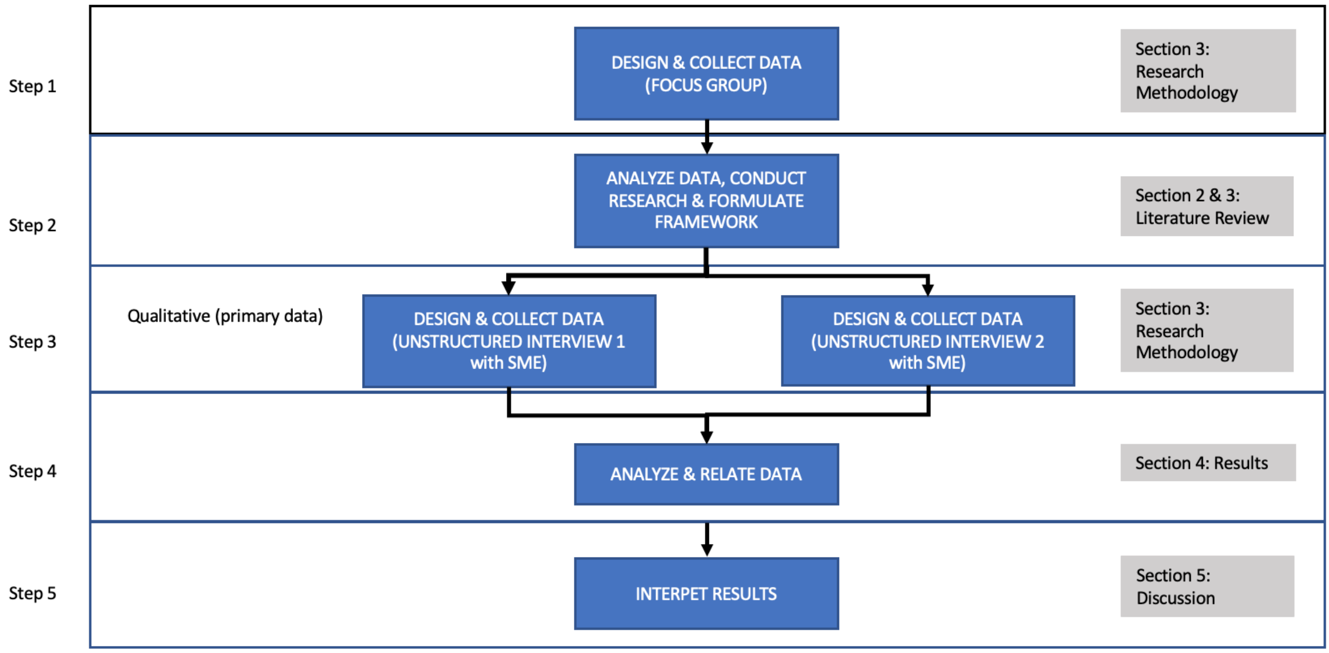


Figure 19: Sequential multi-method research design as described by Bian (116) and the Qualitative Researcher (117)

Step 1: Design & Collect Data (Focus Group)

Purpose: to validate the research questions and objectives and to elicit important themes

In this stage of the research, the expertise of the participants was probed under moderation. For the focus group, 10 participants were invited and the minimum criteria was for all participants to have a Master of Science and.a minimum of 5 years' experience in railway operations or systems engineering. Two of the participants were desired to have over 20 years' experience in systems engineering application and two participants were desired to have 20 years' experience in railway operations and planning. This set of participants was deemed to constitute an expert group capable of providing substantial background to the topic and help with formulating initial themes, areas of agreement and areas of divergence within the Transnet freight railway environment. Of the 10 participants that were invited, five responded that they could participate, These five respondents satisfied the criteria for the focus group above. The five participants that participated have the following credentials:

- Participant 1 - (MSc in SE) senior engineer with 5+ years' experience in capacity planning
- Participant 2 - (MSc in Technology) engineer with 20+ years' experience in technology applications and systems engineering
- Participant 3 - (MSc in SEM) systems engineer with 20+ years' in supply chain management, railway transportation and systems engineering

- Participant 4 - (MSc in Railway Operations Management and Engineering Management) principal engineer with 20+ years' experience in Transnet operations and capacity planning
- Participant 5 - (MSc in Engineering Management) program manager with 20+ years' experience in Transnet operations and capital planning

The focus group took place over the duration of two hours. The purpose of the focus group was fulfilled in that the research question and objectives were validated due to agreement by all participants on the stated question and objectives.

The focus group had the advantage of providing a broad overview of the capacity and freight railway operations in a short period of time. Multiple viewpoints were collected and areas of consensus and lack thereof were identified which was valuable input to the research.

Some challenges experienced included finding a suitable date for everybody to meet and preventing a dominant participant from influencing the other people's opinions and heavily swaying the dynamics of the group.

- Cons: it was challenging to get everyone together at the same time and place and challenging to prevent a dominant participant from taking over the focus group

Step 3: Design & Collect Data (Unstructured Interviews)

Once the conceptual framework was developed, unstructured interviews were used as a tool to validate the developed framework.

Purpose: to get a richer and deeper understanding of topics involved

The desirable criteria for the subject matter experts (SMEs) for each of the one-on-one interviews was as follows: one SME with a BSc and 20+ years industry experience in railway operations or planning and one SME with an MSc with 20+ years industry experience in systems engineering in the transportation environment. The two subject matter experts engaged with that agreed to participate in the research project are described below:

- SME (railway operations and planning) – BSc Hons in Operations Management with 26+ years of experience in Transnet operations and planning
- SME (systems engineering in railways) - MSc in Systems Engineering with 25+ years' experience in systems engineering in the railway industry

<u>Advantages of using unstructured interviews:</u>

- The unstructured interviews have higher validity due to the open nature of the discussion so that participants can influence the direction of the discussion to focus on aspects important to them. This reduced the influence of researcher bias.

- Group think was avoided as people participants are not influenced by other people in the field (this was observed in the focus group and hence one-on-one interviews were deemed more suitable for the validation aspect of the research rather than expert panels)
- It was easier to arrange one-one-one interviews than an expert panel where coordination of schedules to get a team in the same place at the same time is always a challenge

<u>Disadvantages of using unstructured interviews</u>

- It was challenging to directly compare results from the interviews when there were no fixed questions for each interview
- It took some time to find new participants (not part of the initial focus group) who met the criteria for required level of experience and expertise of the participants

The following two sections define the research problem in the context of establishing the conceptual framework. Thereafter, the specific steps applied to transform the literature and research data into the evolved conceptual framework is outlined

3.2 Problem definition

The capacity problem defines the phenomenon experienced in the railway industry where there is an undesirable mismatch between demand and supply – usually where the former exceeds the latter (11). One of the main objectives of the railway operator's capacity planning efforts is to close the gap so that capacity is not excessively under or over supplied as each scenario leads to a dissatisfactory result for a particular sect of stakeholders. The relationships between stakeholders and their interests in the railway network are identified in Table 4 of Section 11.

Increased competition in the market and increased complexity in the structure and operations of the railway network have made it ever more challenging to close the gap between supply and demand through investment in infrastructure and assets alone (see more in Section 1.2). That is, there is a need to focus on operational aspects when planning and operating the freight railway network.

The goal of this research project was to use systems engineering techniques to develop a conceptual framework that will enable understanding and evaluation of operational capacity. In Section 2.2.2, it was established that in systems engineering, the concept of evaluation is tightly linked to the concepts of comparison and decision making – i.e. evaluation is typically conducted to inform selection of the best solution based on a set of established criteria (see Section 2.6).

Conceptual frameworks by definition should facilitate understanding by linking concepts (41). To achieve the aim of the research, the conceptual framework devised should allow for selection of the best alternative based on established criteria. In systems engineering, these criteria shall express whatever constitutes value of the system under consideration by the group of stakeholders. In this case, the system is the freight railway capacity system.

This section describes the methodology that was applied to devise the conceptual framework and perform a first level of validation of its utility. The results of each of the stages are captured in Section

Section 2.1 described the anatomy of a conceptual framework. This deconstruction of attributes of conceptual frameworks enabled a structured research approach. In essence, a conceptual framework lays out the key factors, constructors or variables ('concepts') pertaining to a topic of interest and presumes a relationship between them (118). Jabareen states that grounded theory is an adequate methodology for developing conceptual frameworks since it aims at discovery of theory from systematically obtained data. Furthermore Andersson, Hallberg & Timpka state that grounded theory provides a "context-based, process-oriented description and explanation of the phenomenon, rather than an objective, static description expressed strictly in terms of causality" (119).

For the development of the conceptual framework, Jabareen's conceptual analysis methodology was adopted. Jabareen's conceptual analysis methodology is based on a grounded theory technique that generates, identifies and traces a phenomenon's major concepts. The method involves an interplay between induction, extraction of concepts from data and deduction, which aims at hypothesizing the relationship between them (120).

3.3 The multi-phase conceptual analysis methodology followed for this research project was as follows:

Mapping of the Selected Data Source

The first task was to map multidisciplinary literature regarding the phenomenon in question. This comprised of the following steps:

3.3.1 Participation in an initial focus group on challenges in Transnet's railway operations

In this focus group, the author participated as a listener in a brainstorming session between Transnet personnel and operational capacity subject matter experts including operational managers, capacity planners and focus group facilitators. The brain storming session explored factors that contributed to staged trains, cancelled trains and delayed trains. This exposed the author to challenges to smooth operation encountered within the Transnet environment. This exercise also exposed the author to frequently used terminology surrounding the operational capacity space. The results of the brain storming session are depicted in Figure 20, Figure 21, Figure 22 and Figure 23 of Section 4: Results. Research Results and the contribution of the outcome of the framework is outlined in Section 2.3.6.1.

3.3.2 Conducting an initial literary search and devising research-driving questions to be addressed in initial research

Following the initial focus group, key questions were raised which would be used as driving search terms to find high quality, relevant literature for each of the topic sources. These questions are outlined in Table 7 along with three literature sources that contained substantial data addressing the driving research question. These questions in turn were related to the overall research objectives of this research project as seen in Table 7.

Table 7: Research-driving questions based on initial focus group

Research Objective	Conceptual Framework Driving Questions	Literature Sources
Establish a detailed definition of operational capacity and distinguish from the other types of capacity	What is the definition of freight rail capacity?	An Assessment of Railway Capacity (Abril et al., 2008) Design of Regular Interval Timetables for Strategy and Tactical Railway Planning: Transactions on the Built Environment (Hooghiemstra, J, 1996) Railway Capacity Handbook: A Systematic Approach to Methodology (Kontaxi & Ricci, 2012)
	Is ‘operational capacity’ a term used consistently throughout the freight railway companies globally? What other terms are used instead of operational capacity?	An Assessment of Railway Capacity (Abril et al., 2008) Capacity (UIC Code 406) (UIC, 2004) Railway Capacity Analysis (Lindfeldt, 2015)
To identify the elements comprising operational capacity	How is capacity deconstructed into types?	Railway Capacity Analysis (Lindfeldt, 2015) An Assessment of Railway Capacity (Abril et al., 2008) UIC Code 406 (International Union of Railways, 2013)

	What are the relevant contributors to capacity?	A New Railway System Capacity Model (Roberts et al., 2010) The Capacity Problem (Anderson, 1989) Evaluation of Railway Capacity (Gray, 2013)
	What are the relevant capacity metrics?	The Impact of Operational Strategies and New Technologies on Railroad Capacity (Dingler, 2010) Congested Railways (Lindfeldt, 20120 A New Railway System Capacity Model (Roberts et al., 2010)
To develop a conceptual framework that illustrates the relationship between the elements comprising operational capacity	What are the mechanisms of understanding and evaluation?	Teaching for Understanding (Perkins, 1993) A Conceptual Work on the Engineering of Systems the Top-Down Perspective, with Emphasis on Functional Design and Requirements Analysis (Aslasken, R & Belcher, R, 1992) Evaluation in Systems Engineering (Fabrycky, 2005)
	What are the criteria of a valuable conceptual framework?	Overlooking the Conceptual Framework (Leshem & Trafford, 2007) Boundaries for Thinking and Action (Blackmore & Ison, 1998) Framing and Innocent Concept and Getting Away with It (Weaver-Hart, 1988)
	How is capacity planning conducted?	A New Railway System Capacity Model (Roberts et al., 2010) Capacity Planning Practices Guide (CDC, 2008) Evaluation of Railway Capacity (Gray, 2013)

To analyse the causal relationships between the elements of the railway network	What are the components to be considered when evaluating maintenance allowances?	Rail Network (Transnet Freight Rail, 2010) Survey of railway maintenance activities from a planning perspective and literature view concerning the use of mathematical algorithms for solving such planning and scheduling problems (Lidén, 2014) Computers in Railways XIII: Computer System Design and Operation in the Railway and Other Transit Systems (Brebbia, Tomii, Tzieropoulos & Ning, 2012)
	What are the components to be considered when evaluating operational allowances?	Optimisation of Allowances in Railway Scheduling (Rudolph & Radtke, 2006) Optimal scheduling of track maintenance on a railway network (Zhang, Andrews & Wang, 2013) Railway Capacity Analysis (Lindfeldt, 2015)
	What is scheduling? What is a timetable?	Parametric Modeling in Railway Capacity Planning (Krueger, 1999) Scheduling and Rescheduling of Railway Operations: A Review and Expository Analysis (Narayanaswami & Rangaraj, 2011) Scheduled Service Network Design for
	What factors ought to be considered when devising a timetable?	Timetable Management Techique in Railway Capacity Analysis: Development of the Hybrid Optimization of Train Schedules (HOTS) Model (Pouryousef, 2015) Parametric Modeling in Railway Capacity Planning (Krueger, 1999)

		Application of Scheduled Railways (Magwa, 2015)
	How are timetables evaluated?	Design and analysis of demand-adapted railway timetables (Canca et al., 2014) Evaluation of Railway Performance Through Quality of Service (Lu, 2016) RailNet: A Simulation Model for Operational Planning for Rail Freight (Michal et al., 2016)

As research was conducted, additional literature sources were identified and utilized as part of the conceptual framework as described in the following sections.

3.4 Extensive Reading and Categorizing of the Selected Data

Each of the resources identified in the table above were read critically a minimum of two times, in most cases more, and analysed for key concepts pertaining to the research concepts. This was done concurrently with conducting the more general Literature Review of Section 2. These concepts were then categorized into focus areas for further research (121). This phase of research resulted in competing and contradictory ideas in some instances but the focus was kept squarely on the phenomenon of operational capacity despite there being a number of interesting and informative pieces of literature that were not relevant to the focus of the research. The greater context of each of the concepts may be found in

Using Transnet's operational capacity equation as a point of departure for further research (see below), it was established that allowances emerge as a necessity to buffer against risk where risk is a measure of the potential inability to achieve overall objectives or valued outcomes (122). Thus, in this phase, the high-level factors that compromise operations as well as the factors that impact on the nature and extent of maintenance to be carried out were identified. Furthermore, all of the fundamental concepts emerging from the literature review were categorized into themes and where obvious links occurred, these were brought together. It was not the intention to create any spatial or temporal associations between the concepts – that was objective of phase 3. A mindmap outlining the categorization of concepts performed in development of the conceptual framework may be found in Figure 24 of Section 4: Results.

3.5 Integration of Concepts

This stage involved integrating and grouping topics together that have similarities to each other to reduce the number of concepts under consideration and refinement, to a reasonable number of concepts (118). It also involved amalgamating concepts in the form of temporal and spatial considerations by using the timeline planning process and infrastructure planning process as the basis for aligning the various concepts. Activities that were to be conducted by the same group of people or in association with each other were also linked together. The result of this phase of the research may be found in Figure 25 of Section 4: Results.

3.6 Synthesis, Re-synthesis - Making it All Make Sense

This stage involved synthesizing concepts into a theoretical framework. This process comprised of iteration and repetition in order to devise a general theoretical framework that made sense. Miles and Huberman declare that it is important to know how the theory is constructed as this influences and constrains data collection, reduction and drawing and verification of conclusions (118).

For this aspect of the conceptual framework, the strengths and weaknesses of each of the evaluation models: The Value Model and the HoQ were assessed in order to devise a model that maximised the strengths and mitigated the weaknesses of each model used alone. In the hybridized form of the model, a detailed study on the stakeholder perceived measures of value was conducted in order to establish realistic parameters for each MOE. Furthermore, a detailed analysis of the contributors/risk factors to operational capacity were identified and integrated into the model. For a detailed overview of this artefact, see the text and image associated with Figure 28 in Section 4: Results.

3.7 Validating the Conceptual Framework

Validating the framework was done by conducting a one-on-one interview with a subject matter expert from Transnet to query the validity of the research approach as well as the conceptual framework output from Phase 4 above. This process was conducted by systematically working through the sections of the literature review, discussing findings and requesting feedback and critique on any areas requiring correction, elaboration and additional information. The conceptual framework was explained on a section by section basis, as it is presented in Section 4: Results. The outcome of this section may be found in the Section mentioned above.

3.8 Rethinking the Conceptual Framework

A theory that represents a multidisciplinary phenomenon will always be dynamic and will often be revised according to new insights (123). This is a fundamental aspect to evolving a framework for maximum utility (41). Feedback from Phase 5 was gathered and analysed to determine how the artefacts of the research project may be improved to enhance their utility and accuracy.

The feedback points pertaining to incompleteness or inaccuracies concerning the literature review were simply integrated into the relevant representations whereas feedback that spoke more to paradigmatic aspects within the business view rather than operations view were discussed in Section 5 and formed input to the recommendations for further work. The results of this step are contained in the Discussion in Section 5.

4 RESEARCH RESULTS

This section captures the outcome of the methodological steps described in the Research Methodology. Head in this section corresponds to a related heading in Section 3 with the exception of Phase 6 from Section 3 in which the result of the activity is found in the Discussion (Section 5).

4.1 Mapping of the Selected Data Sources

4.1.1 Participation in an initial focus group on challenges in Transnet's railway operations

As described in the Research Methodology, the first part of the first phase of research involved the author partaking in a brainstorming session between Transnet operations and capacity experts in which the challenges to operations were explored. The contributing factors to cancelled, staged and delayed trains are highlighted in the mind maps shown in Figure 20, Figure 21, Figure 22, Figure 23 (diagrams courtesy of Nicolas Cloete-Hopkins). This brainstorming session was invaluable to the research as it provided the author with insight into the status quo of threats to operations within the Transnet environment and also exposed the author to commonly used terminology. Later in the research phase, these contributors would be recognised as threats to operation and risk sources against which allowances would be applied in order to mitigate against these risks. This is explored further in the subsequent sections.

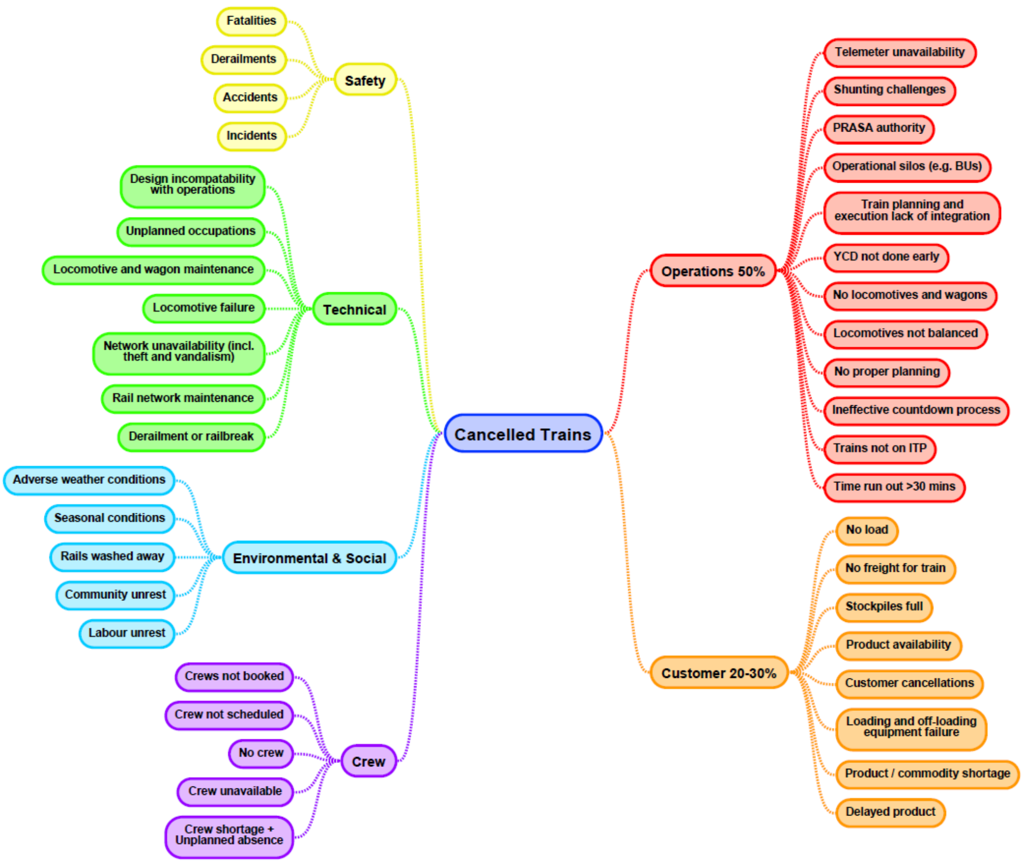


Figure 20: Factors contributing to cancelled trains

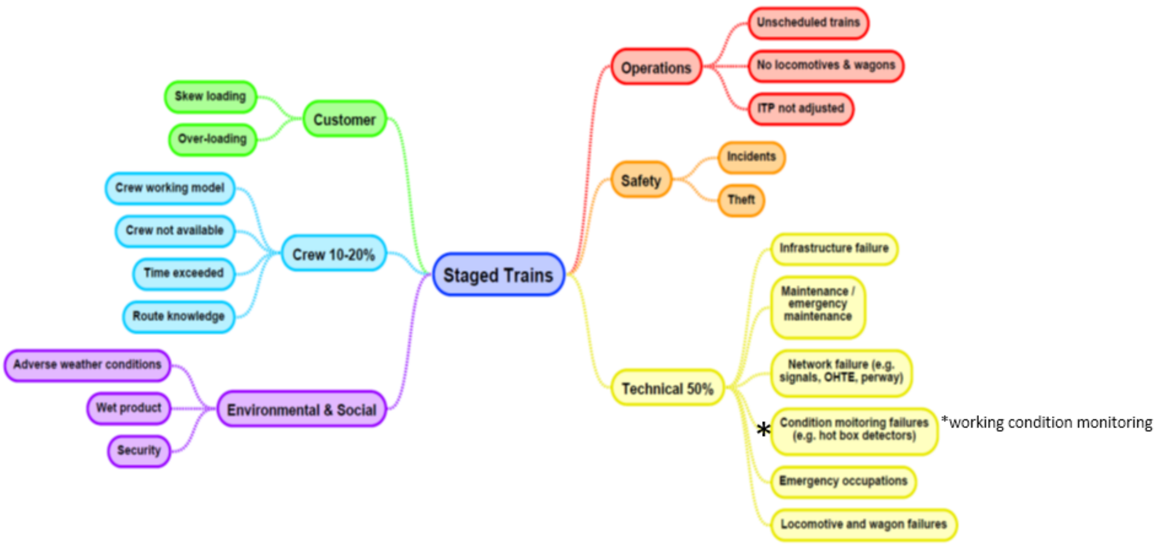


Figure 21: Factors contributing to staged trains

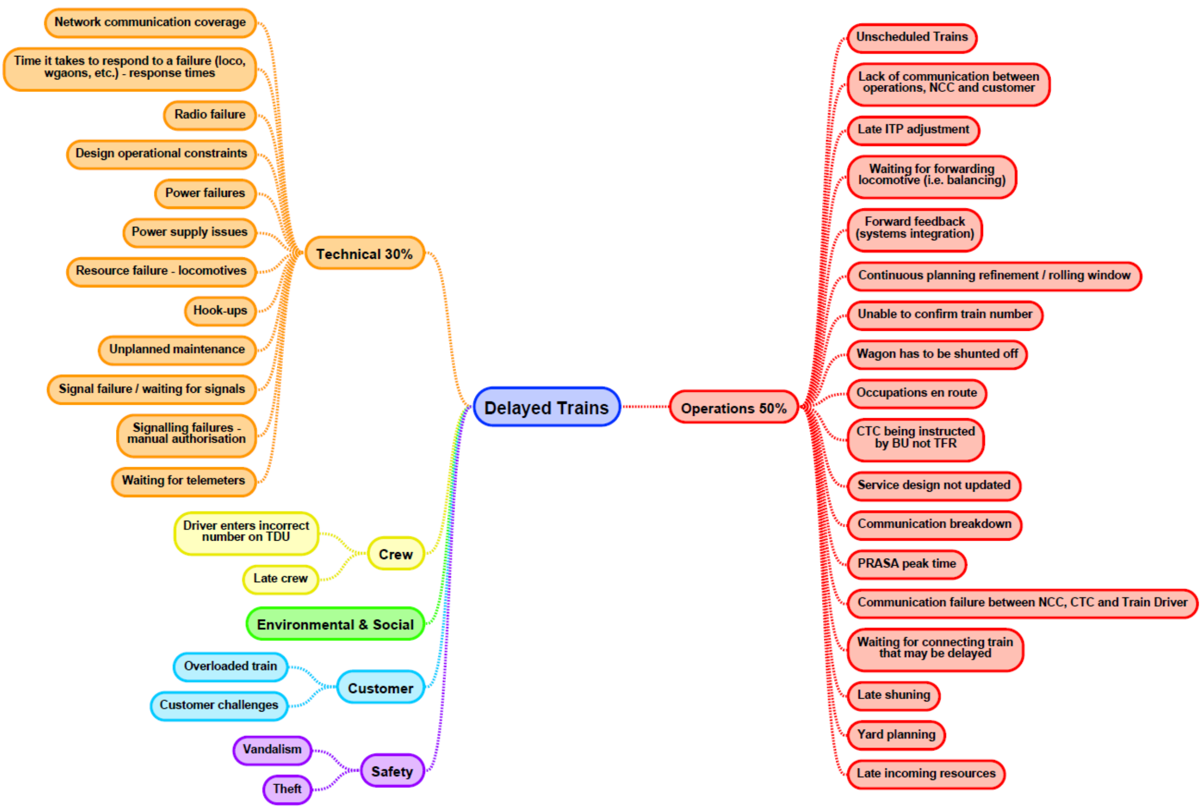


Figure 22: Factors contributing to delayed trains

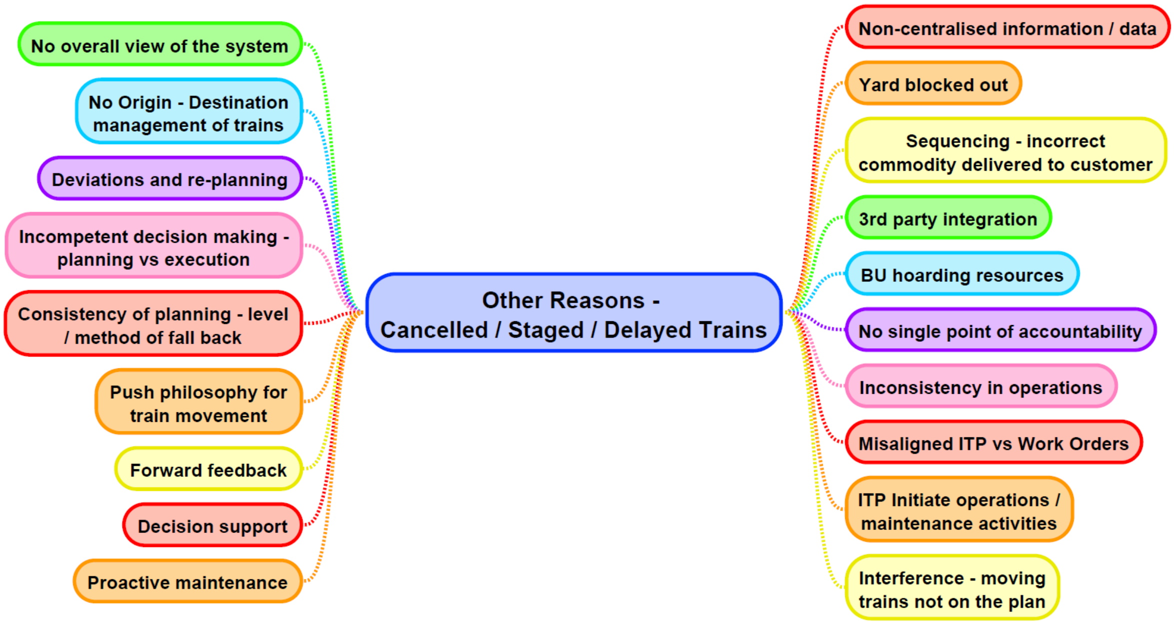


Figure 23: Factors contributing to cancelled/stages/delayed trains (other reasons)

4.2 Conducting an Initial Literary Search and Devising Research-driving Questions to be Addressed in initial Research

The research-driving questions devised in the early parts of the research have been outlined under corresponding heading in Section 3. These research-driving questions helped to identify initial as well as subsequent pieces of literature that would be beneficial to this research project.

4.3 Extensive Reading and Categorizing of the Selected Data

Once relevant pieces of literature were identified as stated in Phase 2 of the research Methodology, they were read several times and key concepts were brought into focus and categorised if they exhibited one or more of the following factors:

1) high level of importance placed on the concept in one or more pieces of literature
2) high degree of repetition of concept across multiple pieces of literature
3) ability of the concept to contribute to understanding of operational capacity in a substantial way

These concepts were organized according to common themes in a mind map as illustrated in Figure 24. Since the text is fairly small in the diagram, the reader is encouraged to view the image via a Google Drive link here. The purpose of this activity was to identify higher level concepts to simplify the elements under consideration in this operational capacity study.

Each of these concepts is described in further detail in the Literature Review of Section 2 however this step of the research methodology expanded upon the Literature Review assessment of available research. This activity involved assimilating ideas between various pieces of literature to establish common higher conceptual ideas in preparation for development of the conceptual framework.

Figure 24: Categorizing of Literature

4.4 Integration of Concepts

This section built directly off the work carried out to categorize the literature by bringing all the higher-level concepts together within the timetable and infrastructure planning paradigm. This activity assimilated information one step further by grouping higher level concepts according to whether they are conducted at the same point in time, by the same group of people or within the same set of constraints. Detail omitted for brevity in the categorizing phase of the research methodology (above) was reintroduced where relevant such as in defining the considerations of the infrastructure planning stages.

The emerging message from this integration of content was that operational capacity is related to the construction phase of railway activity where options to explore methods to address the capacity problem are generated and evaluated. That is, the application of the conceptual framework developed as part of this research is in the tactical planning space. This is delineated by an enclosing rectangle in Figure 25.

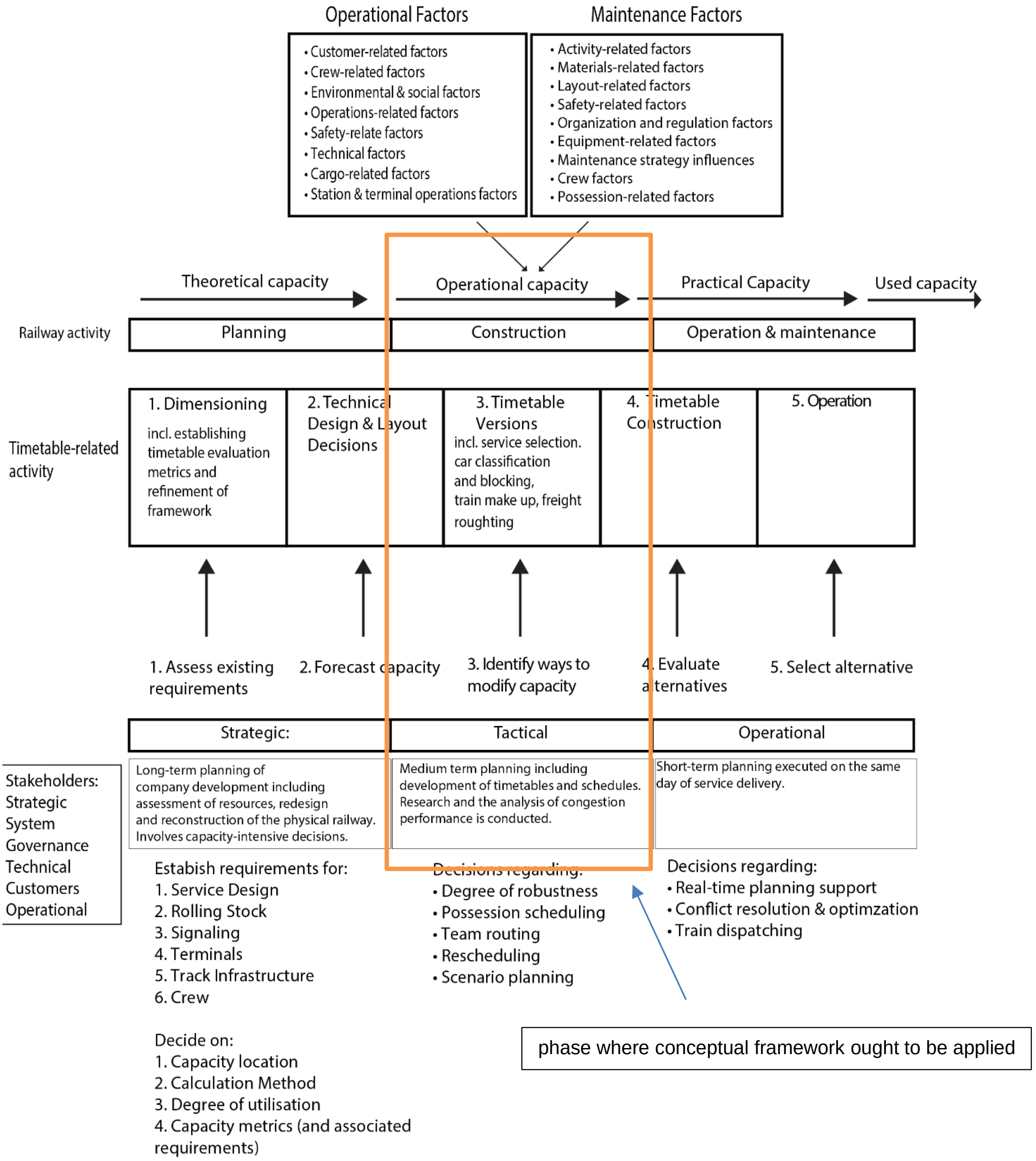


Figure 25: Integration of Concepts

In Section 2.3.2, the importance of demarcating the system boundary in analysing capacity was discussed. In addition, the generic relationship between the system containing system, sibling systems, the system of interest and subsystems was shown via a hierarchical representation of the system. In conducting the research, concepts of the railway were deconstructed from the outside-in. At first, research was conducted to understand the containing system (the context of the railway system) followed by understanding the relationship between elements interacting with the system of interest (operational capacity) and finally by deconstructing the elements that contribute to capacity directly. This is typical of an inductive research approach process (the Research Methodology is covered extensively in Section 3).

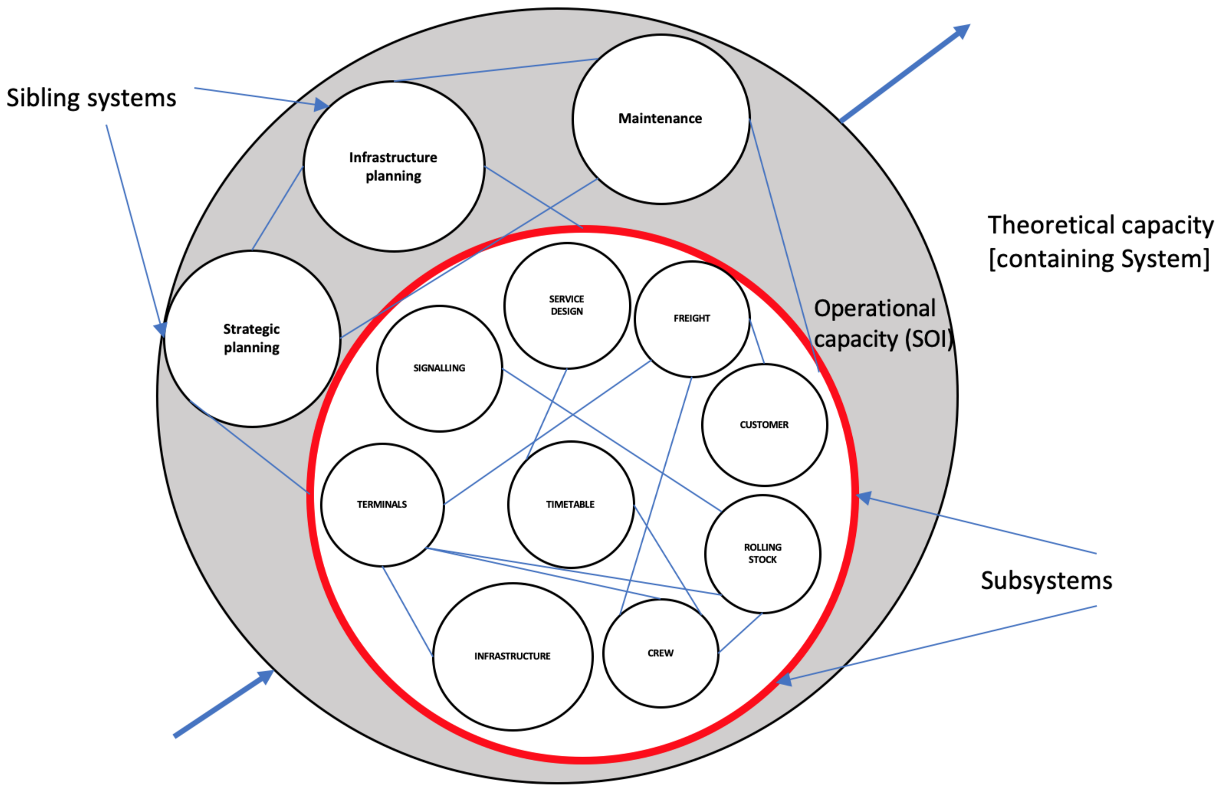


Figure 26: A representation of the system hierarchy with operational capacity as the system of interest

In Figure 24, maintenance, infrastructure planning and strategic planning are shown to have a relationship with the operational capacity system of interest. These elements will have an impact on operational capacity by providing requirements on operational capacity based on stakeholder needs. On the other hand, the terminals, signalling system, service design, freight, customer, rolling stock, crew, infrastructure and timetables directly comprise operational capacity.

The containing system, SOI, sibling systems and subsystems exist within a wider context. This context may be represented by applying the MODAF viewpoints shown in Figure 10 to elicit the stakeholders relevant to freight railway capacity in South Africa This I shown in Figure 27. The organizations and symbols used for each viewpoint are examples one may expect to be relevant for each stakeholder. For example, Eskom is just one example customer of Transnet Freight Railway.

Figure 27: MODAF viewpoints applied to freight railway capacity in South Africa

4.5 Synthesis, Resynthesis - Making It All Make Sense (The Conceptual Framework)

4.5.1 Exploring the mental model behind the conceptual model

The purpose of this section is to describe the content that exists in the conceptual framework. A pivot point in this research emerged from the following quotation from Canca, et al. referenced in the Literature Review:

'Timetables represent the step with most influence on user's perception about quality of the service and thus timetables are a good reference point for capacity evaluation.'

Supporting quotations for this statement from several authors can be found in Section 2.4.1.1.

Launching from Canca et al.'s statement, timetables may be used as a reference point for operational capacity evaluation (which is just one type of capacity). In this sense, the best operational capacity solution may reasonably be tied to the best timetable solution.

The Value Model from Section 2.6.1 allows for selection between alternatives based off of a single set of criteria, specifically the measures of effectiveness (value-adding measures from the perspective of the stakeholder). The HoQ from Section 2.6.2 allows for selection between alternatives (typically competitor products) based on a convolution of customer needs and controlled factors that result in meeting those customer needs.

If the customer needs were replaced with *stakeholder needs* and controlled factors replaced by *operational and maintenance risk factors*, the best (or least risky) timetable could be evaluated (chosen) on the basis of which timetable is least susceptible to maintenance and operational risk thereby requiring a lesser degree of operational and maintenance allowance i.e. having a higher operational capacity.

4.5.2 Short explanation of the conceptual framework

The conceptual framework itself takes the form of an Excel spreadsheet that is a hybrid of a Value Model and the House of Quality, maximizing the strengths and minimizing the weaknesses identified in each of these frameworks. In the resulting framework, the customer needs are more generally, 'stakeholder needs' or timetable evaluation metrics, and the controlled factors are the risk factors that present to a greater or lesser extent for various solutions. The resulting framework:

a) exploits the ability of different units to be brought together in one evaluation activity as is possible in resulting value model
b) allows for the use of utility functions i.e. incorporation of perceived value over a tradeable range
c) allows for separation of priorities
d) provides insight to relationship between timetable evaluation metrics and operational and maintenance risk factors thus enabling a white-box analysis of potential timetables
e) allows for exploration of additional relationships (i.e. relationship between timetable evaluation metrics or between operational and maintenance risk factors)
f) allows for measurement according to each timetable evaluation metric over a much wider range of values for greater clarity in the final result

The spreadsheet, of which the below image is a screenshot of, is available here[6]. A description of each of the numbered sections follows.

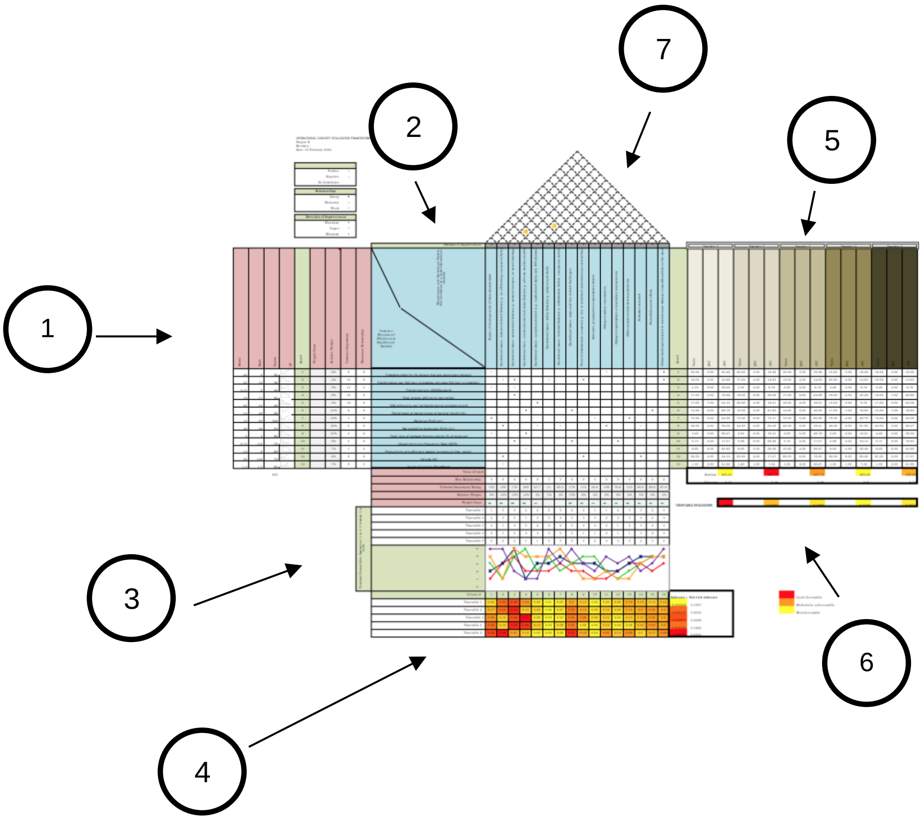


Figure 28: A Conceptual Framework for Understanding and Evaluation Operational Capacity

4.5.3 SECTION 1 - The system effectiveness model

Part 1 conceptual framework is the system effectiveness model. The system effectiveness model was assembled in much the same manner as presented in Section 2.6.1 – The Value Model with a slightly different order of columns. The order of the columns is: Worst, Best, Points, UF, Row, Weight Chart, Relative Weight. Relative Weight correlates to Weight and Weight Chart simply displays a bar graph depicting the Relative Weight. There is also the addition of the Maximum Relationship column which highlights the maximum value in the set of the strength of relationships between the respective stakeholder need and the various controlled factors. The strength of each pair of stakeholder needs and control factors is indicated by the symbols contained in the central relationship matrix which are be explored in Section 4.5.4. The values of each of the stakeholder needs themselves were found through extensive analysis of literature (see further details in Section 4.5.4.4 below).

[6] Please download the file via the link and open the file in Excel.

4.5.4 SECTION 2 - Stakeholder needs (demanded qualities), controlled factors (quality attributes) and the relationship matrix

4.5.4.1 Stakeholder needs

Part 2 of the framework highlights the stakeholder needs and the controlled factors (operational and maintenance risk factors) and the relationship between them. The stakeholder needs themselves correspond to the timetable evaluation criteria highlighted in Section 2.5 on Timetable Evaluation Criteria. This is because, as Poister states, timetable evaluation should produce objective, quantitative information about the expected operational performance of the railway network from the viewpoint of the stakeholders in order to support management in decision making and performance improvement (97) – see Section 2.5 – Timetable Evaluation. Timetable Evaluation of the various timetables, outputs information regarding the risk associated with operating a timetable. An extensive literature analysis revealed the timetable evaluation criteria found in **Table 5**. The Worst value, Best value, Utility Function and measurement units of the MOEs were based on realistic values as gleaned from extensive research (see Section 4.5.4.4 for details).

If the Value model was used on its own, the framework would enable selection of a suitable timetable on the basis of potential timetable performance, without consideration of the associated risk factors. The Value Model would provide a 'black box' view into timetable performance where each timetable is rated against each of the stakeholder measures.

4.5.4.2 The relationship matrix

By introducing the House of Quality element 'controlled factors', the risk associated with each of the operational and maintenance contributors could be taken into account. For each operational and maintenance factor, the importance of each factor is determined by establishing how significant its impact is on each of the stakeholder needs., 'strong', 'moderate' or 'weak'. These importance relationships were allocated by the author based on a fictitious railway network for the purpose of demonstrating the logic of the conceptual framework. The significance of each of the scores determined by the following coarse scoring:

● = strong = 9 points

○ = moderate = 3 points

▽ = weak = 1 point

Once the scores were determined, each of the scores was multiplied by the corresponding weight of each of the stakeholder needs so that the weight of each controlled factor could be determined.

These weightings signify how much of an impact each controlled factor has on overall stakeholder perception of quality. These assessment of each of the timetables is contained in Section 3 of the.

4.5.4.3 The controlled factors

The controlled factors in the roof of the framework were determined via the steps outlined in the Research Methodology of this research report which evolved the information content from Section 2.3.6 – Maintenance and Operational Allowances into useful content for the framework.

The contributors were grouped into relevant categories and described as risk sources where risk is perceived as the probability x severity that a valued outcome will not be met i.e. it is potential loss of a valued outcome (26). Thus, all controlled factors were positioned from the perspective of potentially thwarting capacity of the railway network/line.

The row above the controlled factors signify whether to minimize, maximize or hit the target of each of the controlled factors. Due to each of the controlled factors being stated as a risk factor, the only sensible options in this framework were to minimize or hit the target of each factor as in the instance of safety regulations. There is no direct consequence of the maximize and minimize relationships to the outcome of the framework, but the max/min relationships serve as reminders of the preferred direction of movement of the value (i.e. low or high as possible or stay on target). For example, one would not want to minimize safety but to match perfectly what was necessitated by law or regulatory bodies.

The initial population of the relationship matrix was done purely based on acquired and latent knowledge of the author as a result of learnings gained throughout the project. The purpose of populating the framework with relationships was to illustrate the logic of the framework.

4.5.4.4 The ‘Values’ and ‘UFs’ in the value model

The Worst, Best, UF, Points and Weight of each of the stakeholder needs were proposed based on an extensive literature review conducted around each of the stakeholders needs identified (see Section 2.5 – Timetable Evaluation). The following paragraphs describe the methodology behind devising the Utility Functions.

1. Timetable stability/robustness (% of delays that are secondary delays)

The value in using secondary delays as an indication of timetable stability is that it indicates the delays caused by the interaction of trains with other trains due to occupational conflicts (53). This will be affected by degree of heterogeneity in the average speed of trains, what type of signalling system is used, allowances (extra time in the timetable added to scheduled time) and buffer times (time allocated between trains in the timetable) used to absorb the impact of primary disruptions (53).

Proposed utility function:

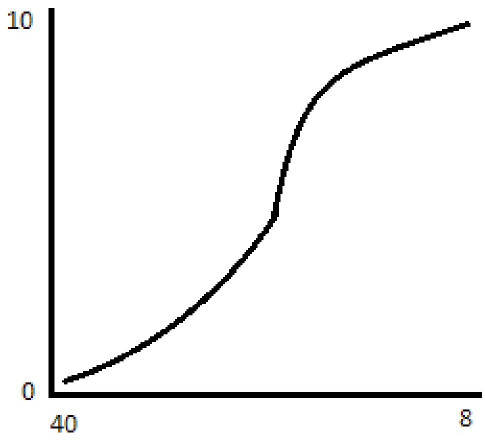


Figure 29: Utility function – timetable stability (% of delays that are secondary delays)

This utility function (read from left to right of the x - axis) suggests that for the worst to best range from 40% to 8%, that the perception of value increases at first exponentially with a gentle relationship and then at about 20% secondary delay, the perception of value increases sharply and then starts to taper off at a decreasing rate, signifying an ever-lower return on operational change for a decrease in secondary delays. There is a 'knee' in perceived value that indicates that past a certain point of stability, resources applied become less consequential from the stakeholder's perspective.

2. Average freight delay per 100 train kilometres

Freight delay per 100 train kilometres is a normalised measure of delay. This is useful since freight train mileage can fluctuate with demand, so a normalised measure enables better comparison between timetables (124). This includes all types of delay including delays arising from network disruptions, secondary delays and delays with dispatching and receiving of goods. This value gives insight into train performance throughout the network, from origin to destination (124).

Freight delay is impacted by a variety of operations including network, port and terminal operations. Freight delay per 100 kilometres tends to peak around colder months so between the second and thirds quarter of the year, it is expected to be at its highest (125).

Proposed utility function:

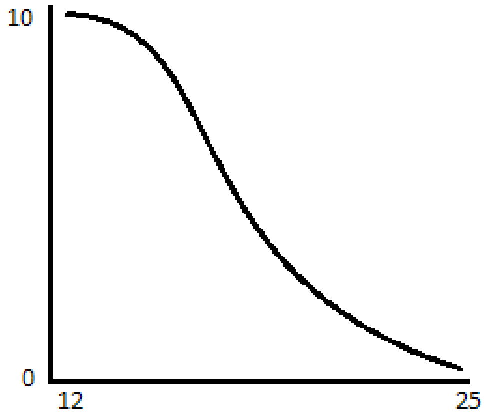


Figure 30: Utility function – average freight delay per 100 train kilometres

This utility function (read from right to left of the x - axis) suggests that for every decrease in delay from 25 minutes to 18 minutes, the perception of value increases at an increasing rate, thereafter for every decrease in delay from 18 minutes to 12 minutes per 100 train kilometres, the perception of value increases at a decreasing rate. This indicates that there is a 'knee; close to 12 minutes per 100km for which further effort to decrease delays becomes less consequential to stakeholders.

3. Freight density (GTK/Routekm)

This value gives an indication of the usage of the railway network – in Transnet's usage of Gross Tonne Kilometres (GTK), the weight of the train itself is omitted so this gives an indication of the economies of freight. A higher value would mean that it is being more effectively used (126).

Pienaar, et al. state that economies of freight density are capitalised when the total cost to transport units of freight from origin to destination are decreased by increasing utilisation of rolling stock and infrastructure within a market area (125). The economy of freight density is affected by the capacity of technology to carry and handle large loads, the loading and unloading times, the amount of use obtained from vehicles and the degree of traffic consolidation which involves loading and routing in consolidated groups for optimal efficiency (127).

Proposed utility function:

Figure 31: Utility function – freight density (GKT/Routekm)

This utility function (read from left to right of the x - axis) suggests that for every incremental increase in freight density, the perception of value increases linearly over the entire range of acceptable values from 5.15 to 6 GTK/Routekm. That is, there is a constant gain in value for every operational change implemented to increase freight density.

4. Total energy efficiency (ton/GJ) includes fuel and electricity

This is the amount of energy required to move a tone of goods over a distance of 100km. Infrastructure and the design of the vehicle play a major role in energy efficiency (127). This includes use of regenerative breaking and aerodynamics of the train (126).

Proposed utility function:

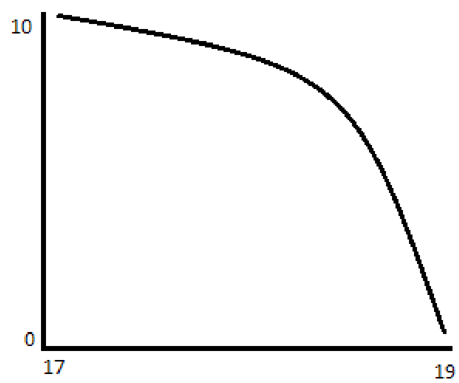


Figure 32: Utility function – total energy efficiency (ton/GJ)

This utility function (read from right to left of the x - axis) suggests that for every incremental decrease in fuel usage (an increase in fuel efficiency) from 19 to 18.2, the perception of value increases at an essentially linear rate, thereafter the perception of value increases at a decreasing rate from 18.2 to 17. This suggests that at a certain ‘knee’ point in efficiency, the resources committed to increasing efficiency have a decreasing rate of return for stakeholders.

5. CO_2 emissions per net freight tonne km (g/tonne-km)

The amount of CO_2 emitted is very sensitive to load factors and use of electricity.

Proposed utility function:

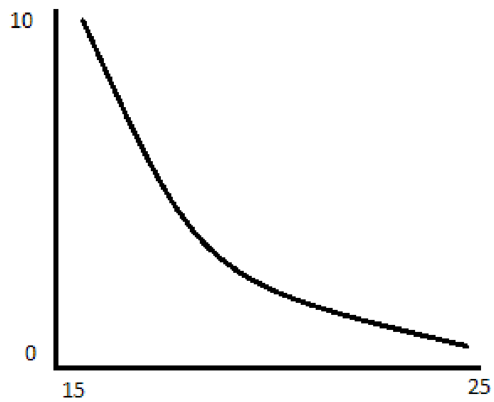


Figure 33: Utility function – CO_2 emissions per net freight tonne km (g/tonne-km)

This utility function (read from right to left of the x - axis) suggests that for an incremental decrease in CO_2 emissions from 25 to 19, the perception of value increases at a low rate, thereafter as the emissions decrease from 19 to 15, the perception of value increases at an increasing rate. That is, for every resource invested to decrease emissions from 19 to 15, the perception of value gained is higher than for the decrease from 25 to 19.

6. Percentage of market share (%)

In Transnet, the main types of cargo transported include (128):

i) Sugar
ii) Cement
iii) Coal
iv) Grain
v) Car parts
vi) Liquid bulk
vii) Zinc

A questionnaire to a large group of freight customers conducted by Mathabatha indicated that customers place high importance on service delivery in addition to the ability to transport a quantity of goods from A to B (125). In addition, transportation costs play a factor in general, the percentage of market share will also be affected by the railway operator’s operating and industrial power (125).

Proposed utility function:

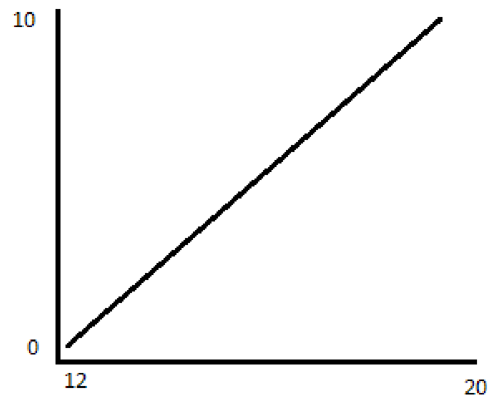


Figure 34: Utility function – market share (%)

This utility function (read from right to left of the x - axis) suggests that for an incremental increase in market share, the perception of value increases linearly throughout the range of acceptable values. That is, there is a constant increase in perception of value gained for every resource invested change to improve the market share over the range of reasonable and acceptable values.

7. Revenue (R million)

Operators should seek to maximise revenue while maintaining an acceptable level of service (70). The goal is to find the optimal amount of cargo to travel along each path (96). de John states that developing an effective pricing strategy and executing it correctly is a complex task but doing this successfully or not can be the difference between generating a profit or a loss (129). With strategic pricing, railway operators can use pricing as an opportunity to defend and expand their market share and increase revenue. Part of developing a pricing strategy involves consideration of operational feasibility of moving a train along a certain path (129). The timetable can have a direct impact on revenue as it directs operational feasibility.

Proposed utility function:

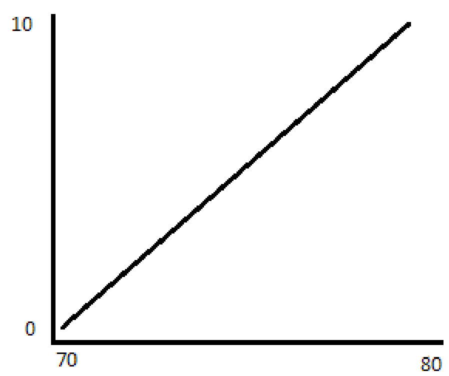


Figure 35: Utility function – revenue (R million)

This utility function (read from right to left on the x - axis) suggests that for an incremental increase in revenue, the perception of value increases linearly throughout the range of acceptable values. That is, there is a constant increase in perception of value gained for every resource invested to improve the revenue to the operator, for the range of acceptable and reasonable revenue outcomes.

8. Net operating expenses (R million)

Operating expenses have a direct effect on profitability of network operations. The goal is to minimise operational expenses but not to the point where quality of service and other performance factors is negatively affected (8). The scope of affected costs includes:

I. Maintenance costs wagons and loading units (time, distance, number of loading runs)
II. Rental costs, wagons (time)
III. Driver (time)
IV. Shunting (locomotive, driver, shunter – time)
V. Energy (distance, weight, speed)
VI. Accident fee (distance)
VII. Marshalling (per occurrence and wagon)

Proposed utility function:

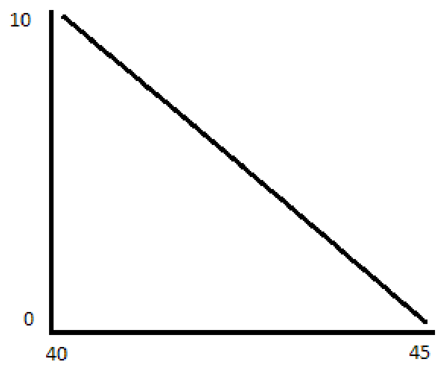


Figure 36: Utility function - net operating expenses (R million)

This utility function (read form right to left along the x - axis) suggests that for an incremental decrease in costs, the perception of increased value is constant throughout the range of acceptable values thus a change in operations resulting in reduced operating expenses will produce a constant positive increase in impression of value by stakeholders.

9. Total loss of damage from accidents (% of revenue)

Damage from accidents can result in human injury or not. Regardless of the range of affected elements from the accident, damage results in an expenditure of finances that could have otherwise been used for upgrades or asset acquisition (130). Contributors to railway accidents include (131):

- Track, railway bed and structural issues such as damaged/improper track geometry, rail joint bar, rail anchoring, frog switches and track appliances
- Signal and communication errors
- Operational factors including braking, poor physical condition of employees, incorrect switching rules, handling and speed of trains
- Mechanical and electrical failures such as brakes, axles and journal bearings, wheels, locomotives, doors and track components

A timetable should be designed and implemented so as to reduce the risk of damage in accidents. It is desirable to have total loss of damage from accidents as low as possible.

Proposed utility function:

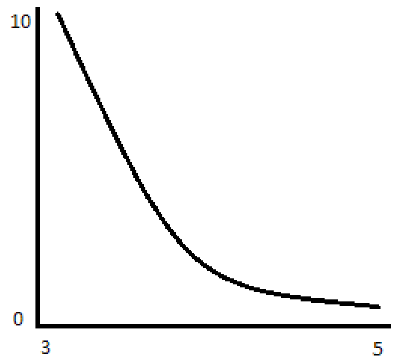


Figure 37: Utility function - total loss of damage from accidents (% of revenue)

This utility function suggests that for an incremental decrease in total loss of damage from accidents, the value increases almost linearly and at a fairly low rate for the range of 5% to 4% but once the total loss of damage from accidents reduces from 4% and lower, the perception of changing value increases steeply i.e. the change from 4% to 3% presents greater value than that from 5% to 4%.

10. Disabling injury frequency rate (DIFR)

This is a measure of the number of deaths or disabling injuries per 200 000 employee hours of exposure (3). This could be any work-related injury that results in permanent, partial or temporary disability or loss of life. These injuries may be caused by a similar array of factors as for that of the accidents above. Disabling injuries arise from accidents and should be avoided as far as possible (119). Timetables that minimise the risk of disabling injury are preferential.

Proposed utility function:

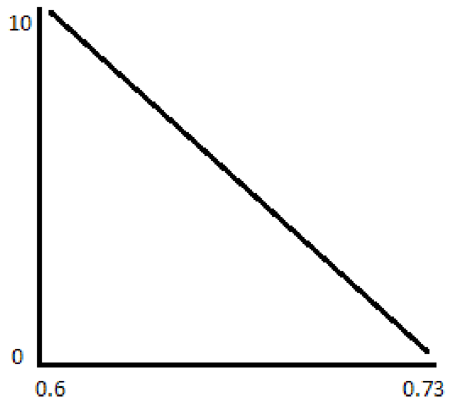


Figure 38: Utility function – disabling injury frequency rate (no./200 000 employee hours of exposure)

This utility function (read from right to left along the x – axis) suggests that for an incremental decrease in the DIFR, a constant increase in perception of value gained is found for the entire spectrum of acceptable and reasonable values. Thus, any additional resources spent to decrease the disabling injury frequency will be perceived favourably by stakeholders.

11. Productivity and Efficiency - Wagon turnaround times (WTT)

Wagon turnaround times are affected by operational constraints such as (132):

- Time for receipt and handing over of groups of consolidated trains
- Splitting and reassembly of consolidated wagons
- Availability of plant locomotives
- Availability of cranes for loading at the mills
- Matching weight and adjustments of wagons within turnaround times

In 2016, Transnet announced a new business strategy to reduce average wagon cycle/turnaround time by 20% (2018). At present, Transnet wagons are being overutilized and compromised and do not meet scheduled maintenance time as a result. Transnet is focused on improving wagon turnaround time while sustaining operational efficiency, production and quality customer service (133).

Proposed utility function:

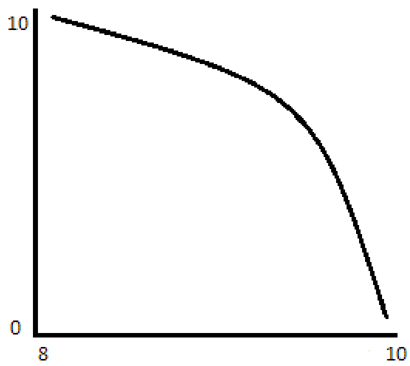


Figure 39: wagon turnaround times (days)

This utility function (read from right to left on the x – axis) suggests that for an incremental decrease in wagon turnaround time from 10 days to 9, the perception of value increases at a steady, fairly high rate. Thereafter, a change in operational factors to produce a lower wagon turnaround times will continue to bring an increase in perceived value but at a decreased rate of return. This implies that there is a 'knee' point above which any additional resources spent to decrease wagon turnaround times will have a decreasing return on investment.

12. Volume (metric tonnes)

Transnet has reported that in the past, designing a timetable by defining arrivals and departure times has aided in increasing the volume of the goods transported from origin to destination (134). Thus, scheduling of the train movements, and the ability to fulfil those scheduled movements is directly dependent on the timetable. Volume transportable (throughput) is the most widely adopted concept of capacity (80). Volume of freight carried is a measure of the physical efficiency of the railway network which means that maximising volume transported means maximising profit. There is a limit beyond which the level of service may be affected if resources are strained and if the timetable does not offer a sufficient level of stability.

Proposed utility function:

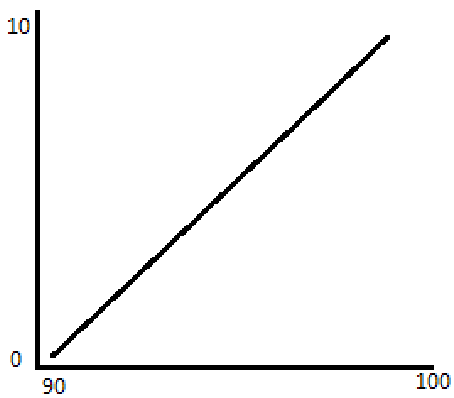


Figure 40: Utility function - volume (metric tonnes)

This utility function (read from left to right along the x – axis) suggests that for an incremental increase in volume within the reasonable and acceptable range of values, the perception of value increases linearly i.e. there is a constant rate of increase of perception of value as each resource is committed to produce an increase in volume transported.

13. Asset utilisation (Gtkm/Ntkm)

Sogin, et al. affirm that asset utilisation is a measure of how effectively the physical resources are being used during operation (135). Asset utilisation is also a primary indicator of capacity – under-utilisation signifying potential for increased use (136). Asset investments can often be postponed if more efficiency can be gained out of the physical infrastructure. Several factors have a direct effect on asset utilisation including dwell time in terminals, blocking time, track miles and the number of idle locomotives (135).

Proposed utility function:

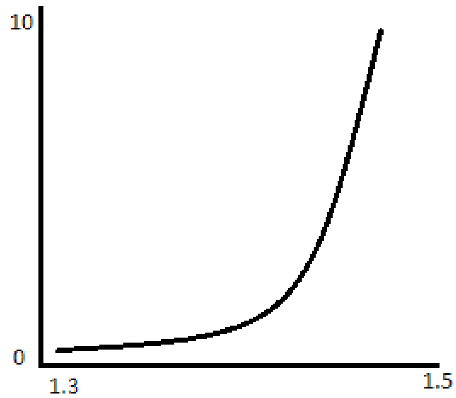


Figure 41: Utility function - asset utilisation

This utility function suggests that for an incremental increase in asset utilisation from 1.3 to 1.4, the perceived value increase is basically constant at a fairly low rate and then starts to increase significantly around 1.4 so that every operational change implemented to increase asset utilisation from 1.4 Gtkm/Ntkm to 1.5 Gtkm/Ntkm produces a significant corresponding increase in perception of value by stakeholders.

4.5.5 SECTION 3 - Technical competence assessment area

The technical competence area contains the evaluation of each of the timetables against each of the operational or maintenance factors. A scale of 1 – 5 as is customary for Hoods was used since high granularity requires in-depth knowledge to be useful. In this case, numbers were randomly generated as applying the framework to actual timetables was beyond the scope of this Conceptual Framework development. The coloured graphs visually display the scores of the performance of 5 timetables against each of the operational and maintenance risk areas. The colour graphs act mainly as quick references during discussion between decision makers regarding which timetables perform best in various areas.

4.5.6 SECTION 4 - Operational and maintenance risk calculations

Underneath the colour graphs, is the operational and maintenance risk calculation are which is performed on as relative basis. Here, the scores of each of the timetables against each of the operational and maintenance factors were convolved with each of the operational and maintenance factor weightings from Section 2. The representative unit risk was calculated by appropriating each of the weightings in to the relative weighting so that the sum = 1. This allowed for combining the opportunity and risk of each of the timetables. Here, higher numbers represent higher risk because of the phrasing of each of the controlled factors. In displaying the results of the calculation, yellow implies most favourable, red least favourable and orange implies medium levels of satisfaction, on a comparative basis.

4.5.7 SECTION 5 - Value model application

For the right-hand side of the framework, the value model was applied to 5 fictitious timetables. Numbers within each of the Worst to Best value range were postulated since a timetable meeting the requirements would fall within the range [Worst; Best] where Worst is the minimum acceptable criteria and Best is the maximum feasible result. The sum of each of the Absolute Value Contribution (AVC) columns indicate the anticipated value of operating each of the timetables. This value is only of most significance when used in comparison with other values (see Section 4.5.7 – The Value Model for more details). In effect, these values represent 'opportunities' of the timetable to achieve or exceed valued outcomes (i.e. the opposite of risk). These values were refined to a unit basis so they could be combined with the risk factors from the operational and maintenance risk calculations to get an overall impression of relative value of the various timetables. Again, yellow implies most favourable, red least favourable and orange implies medium levels of satisfaction, on a comparative basis.

4.5.8 SECTION 6 - Timetable evaluation & selection

Here the opportunity of the timetable was subtracted from each of the related risk values to give an overall impression of risk (there will always be more risk than opportunity which is indicated by the fact that projects fail much more frequently than they succeed) (31) (26). Since each of the risk indicators were in unit form, they could comfortably be amalgamated to determine which timetable would have the best balance of risk to opportunity. As with the previous opportunity and risk calculations: yellow implies most favourable, red least favourable and orange implies medium levels of satisfaction, on a comparative basis.

4.5.9 SECTION 7 - Relationships between controlled factors [7]

The purpose of the relationships between the controlled factors are to signify potential coupling between various controlled factors. These do not directly contribute to the selection of the timetables but may be used in a more detailed levels of analysis of the railway network where coupling may become more significant. For the purpose of this research report, these relationships were postulated by the author to illustrate the logic of the framework.

4.6 Validating the Conceptual Framework

In order to validate the conceptual framework, an interview was held with a subject matter expert Transnet employee with several years of experience with freight railway operations and capacity. The transcription of the interview is found in Appendix C. The findings of the research as well as the conceptual framework was presented to the subject matter expect for feedback and critique. For the purpose of this section, the main discussion points have been organized as questions and answers in this section. If further detail or context is requested, the reader is encouraged to refer to the full transcription. In the following series of questions and responses, RK represents the initials of the author while TE abbreviates ‘Transnet Employee’.

4.6.1 Question 1: Capacity definition

RK: Transnet’s operational capacity definition is not universal – the term, ‘practical capacity’ is used more commonly throughout the world to describe capacity adjusted for maintenance and operational allowances but not conditional allowance. There is no consensus in the definition of capacity but it is acknowledged that capacity concerns acceptable services levels and costs, present and projected demand, schedule and operating plans, defined thresholds and variability on the basis of conditions. Is the description of capacity accurate to your understanding?

TE: Yes, this makes sense.

4.6.2 Questions 2: Capacity types

RK: Is the dissection of capacity according to capacity location, calculation method and degree of utilisation useful in contextualising capacity and setting up a boundary of study? [In reference to Table 3]

TE: I think the headings are useful but there is a little bit more to the story pertaining to location. There are two primary points of interest when studying railway networks:

a) The capacity of the track is of significance. Usually when we consider capacity of the track, Transnet Freight Rail (TFR) thinks about volume over distance – a railway operator wants to move the maximum volume over the longest possible distance to reduce unit cost.

b) The capacity of the yards is also of significance. For the capacity of yards, we think in terms of the number of units processed per unit time. Yards are responsible for building and breaking up trains. The capacity of the network is constrained by the maximum amount of trains that can be processed by the yard.

So, network capacity is about the ability of freight to be constantly moving and about eliminating standing time or dwell time. It is more about velocity than speed.

When it comes to line capacity, loops are essential for trains to pass each other (especially for single track lines). For double track lines, signalling is introduced so that trains do not collide. For line capacity, two important considerations are:

a) The distance between loops (the greater the distance between the loops, the further apart trains ought to be run)
b) The headway between trains (the larger the headway, the further apart trains ought to be run)

4.6.3 Questions 3: Capacity metrics

RK: What are your impressions of the capacity metrics: throughput, level of service and asset utilisation? [In reference to Table 4Table 3]

TE: I think that the three paradigms are suitable. However, for throughput, velocity is an important concept that emerges from the desire to minimise idle time and maximise moving time as expressed previously. Engineering for speed is a lot more expensive (this requires more powerful trains and more sophisticated braking technologies) however focusing on eliminating standing time has a much greater return on investment.

For level of service, I believe that (on-time, in-full) OTIF is an important measure. From a customer perspective, they want to make sure that not only is cargo delivered on time but that it is delivered altogether. Sometimes with the way that trains are made up and broken up, it is possible to have cargo delivered at different stages but this may or may not be acceptable the customer (it mostly is not).

4.6.4 Question 4: Stakeholders of the railway environment

RK: What are your impressions of the breakdown of stakeholders described? [In reference to Figure 10]?

TE: I think it is good. There are certainly many players involved in the transportation industry. I believe this is corroborated by the slide below:

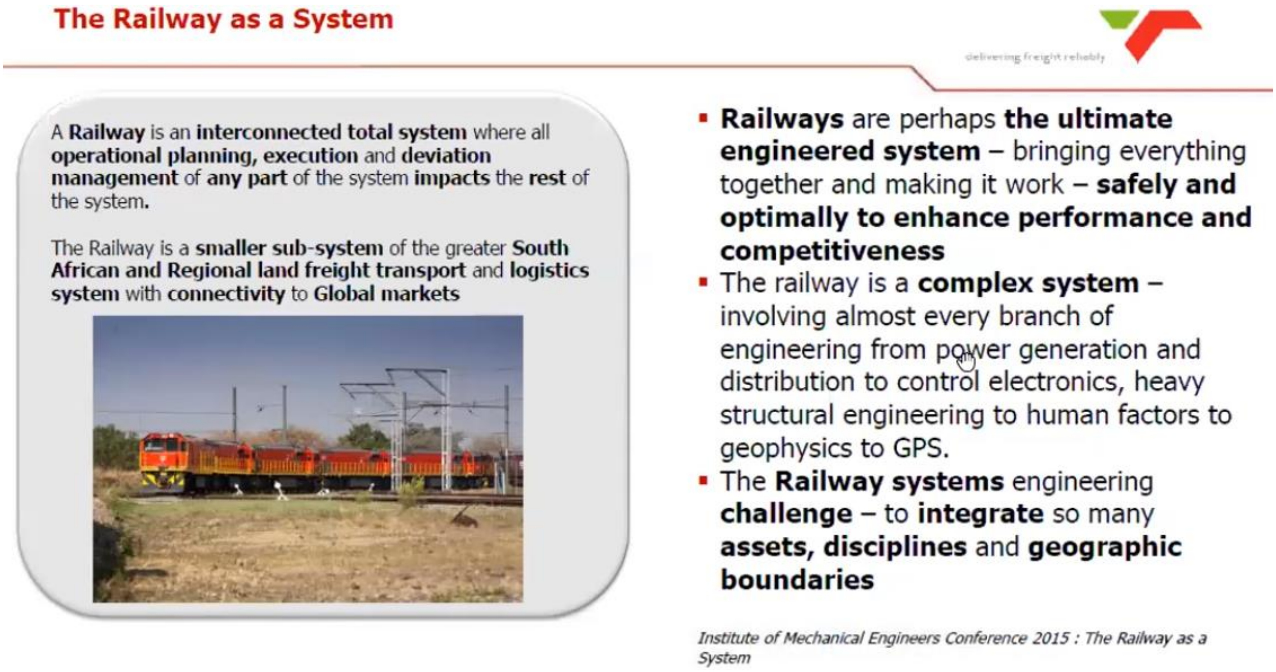


Figure 42: The Railway as a system

(Adopted from Transnet Employee (shared with permission))

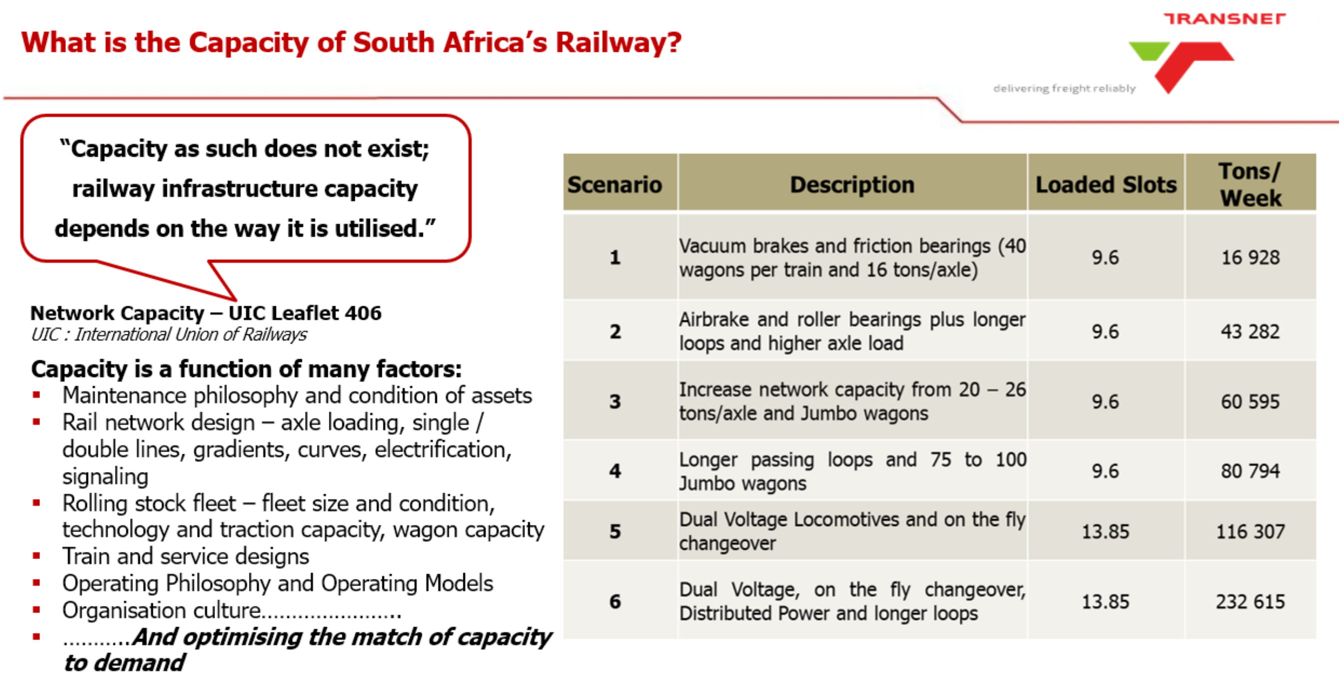
Furthermore, this breakdown in stakeholder perspectives is very useful for Transnet that has a different role in different spaces. In some spaces, Transnet is infrastructure- owner and in some spaces, Transnet is operator on the network. In the near future, Transnet will be even more complicated in its stakeholder structure as it is starting to offer the consolidation services that some of its customers do in order to present traffic in a way that makes sense i.e. Transnet is about to start competing with its customers. I believe this is corroborated by a slide I created for a presentation a few weeks ago in which the complexity of the railway network is explored. Please see the following slide.

4.6.5 Question 5: Challenging the 65% Rule

RK: Operational capacity is the capacity that is available after maintenance and operational allowances are afforded - Transnet takes this value to be 65% in general. Operational capacity is the pool of capacity available for allocation in a timetable so it is of high significance. Research shows that achieved levels of operational capacity lie between 65% and 75% (8). Even in Transnet's ore line, operational capacity levels of 75% or above are achieved consistently. This presents quite a large range of achieved operational capacity. In freight railway capacity, leveraging even a 1% capacity increase can be of substantial value. The proposition of this research is that, instead of basing operational capacity on a percentage of theoretical capacity and proceeding, the focus when determining which timetable to operate, should be which timetable presents the greatest probability (or lowest risk) of achieving stakeholder value outcomes. What are your general thoughts about challenging the approach of taking operational capacity to be 65% as standard step in generating a timetable?

TE: I think that this is a very pragmatic approach to adopt. I also think that the ability of this framework to be effective depends on three things: the level and standard of engineering, level and standard of maintenance, level and standard of predictive technologies. On the ore line as you have mentioned, a lot of actions have been taken up to support preventative maintenance and the schedule has been designed to have fixed maintenance slots. The ore line turns out to have an operational capacity of 70 – 75%. The ore line runs 6 trains per direction per day, the trains are 2.5 hours apart and there is which leaves a 6- or 7-hour gap where maintenance can be conducted. Maintenance is conducted as follows: two train slots have been allocated as moving maintenance slots. In the morning, the southern part of the line is maintained while freight is transported on northern part of the line. At about 1pm, maintenance starts on the northern part of the line while freight is being delivered on the southern part of the line. In this way, maintenance is conducted without disruption. On other networks, there is less flexibility to build in than with predictive maintenance.

There is something else I want to draw your attention to, please consider this slide I recently presented in a Capacity 101 presentation recently.



Scenario	Description	Loaded Slots	Tons/ Week
1	Vacuum brakes and friction bearings (40 wagons per train and 16 tons/axle)	9.6	16 928
2	Airbrake and roller bearings plus longer loops and higher axle load	9.6	43 282
3	Increase network capacity from 20 – 26 tons/axle and Jumbo wagons	9.6	60 595
4	Longer passing loops and 75 to 100 Jumbo wagons	9.6	80 794
5	Dual Voltage Locomotives and on the fly changeover	13.85	116 307
6	Dual Voltage, on the fly changeover, Distributed Power and longer loops	13.85	232 615

Figure 43: Illustration of the impact of capital investment on capacity creation

(Adopted from Transnet Employee (shared with permission))

Note firstly, UIC's statement that 'capacity as such does not exist; railway infrastructure capacity depends on the way it is utilised'. I agree strongly with this statement and I think this is what your research alludes to, as well. I will now explain what the 6 different scenarios on the slide describe and why this is significant:

1. In Scenario 1 – vacuum brakes are used with a limit of 40 wagons per train and 16 tons per axle. If there are 9.6 train slots available, this gives a throughput of 16 928 tons that are moved.
2. In Scenario 2 – wagon technology is improved by replacing vacuum brakes with air brakes and friction bearings are replaced with roller bearings and with the same number of available slots, throughput is more than doubled [42 282 ÷ 16 928 = 2.56]
3. In Scenario 3 – wagon technology is improved again by using jumbo wagons and increasing the network capacity from to between 20-26 tons per axle. This more than trebles the initial amount of throughput. [60 595 ÷ 16 928 = 3.58]
4. In Scenario 4 – loop extension is applied so that longer trains can enter the line and this increases throughput by 4 times the initial amount. [80 794 ÷ 16 928 = 4.77]
5. In Scenario 5 – the technology of the locomotives is improved by using dual voltage locomotives capable of traversing AC and DC electrical sections which reduces 'standing time' of the train as changeovers can be made rapidly. It usually takes roughly 2.5 hours to build up air in the train once it has been exhausted when it is brought to a stop. By implementing this new technology, this multiplies the initial throughput by more than 6 times the initial amount [116 307 ÷ 16 928 = 6.87]
6. Lastly, by applying a hybrid approach to improving wagon technology and locomotive technology i.e. employing dual voltage, on-the-fly changeovers, distributed power (which introduced locomotives between trains which ultimately shortens the acceleration and breaking curve) and longer loops; the throughput is increased by more than 13 times the original amount. [232 615 ÷ 16 928 = 13.74]

The overall message of this slide is that tactful trade-off studies should be conducted between solutions comprising all possible means of closing the gap between capacity and demand, bearing in mind available resources and capital. The main reason for capital over-expenditure in the past is lack of structured decision-making processes. I also want to draw your attention to the influence of organisational culture on capacity.

The takeaway is that: capacity creation is best achieved through a combination of operational and maintenance and measured capital investment to deliver customer demand service. Your research does well at highlighting the former, I am just bringing your attention to the latter. The following slide brings these concepts together.

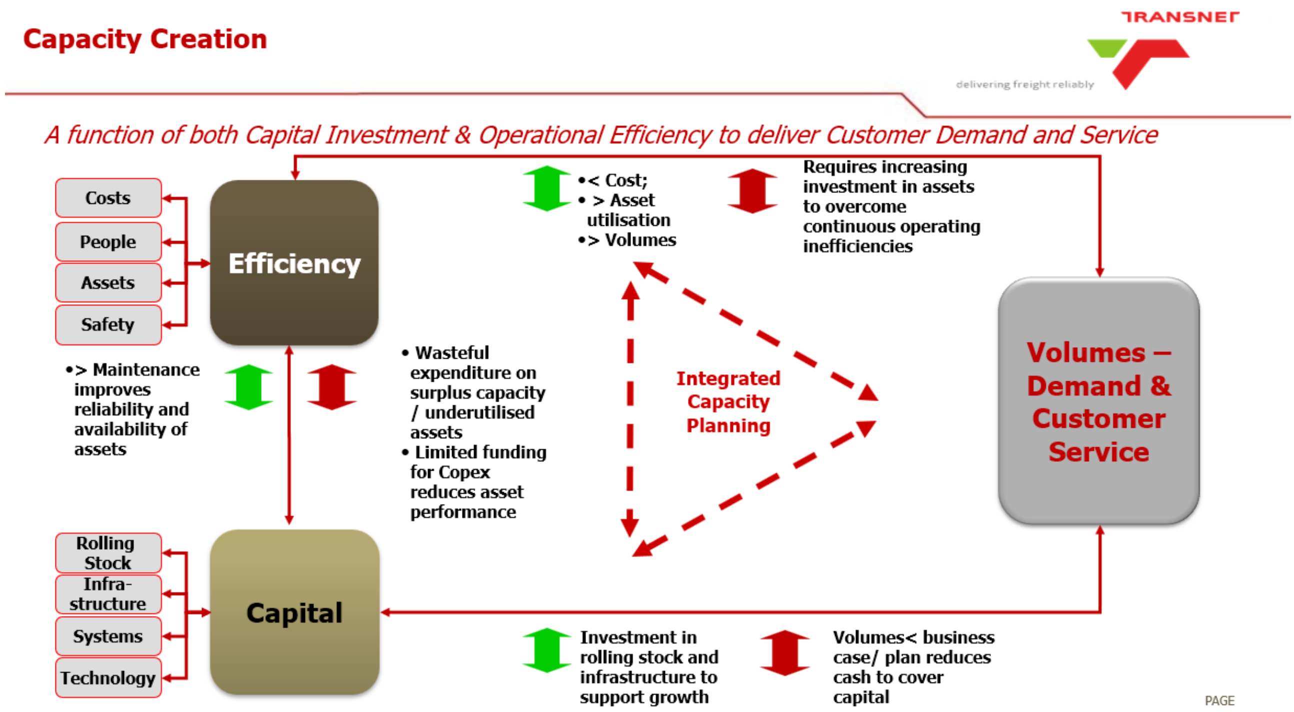


Figure 44: Significance of capital investment and operational and maintenance efficiency in delivering customer demand and service

(Adopted from Transnet Employee (shared with permission))

This particular exercise led to a number of capital projects being halted, in particular a project that had a budget of R20bn over 7 years but it was reduced to R3.5bn over 7 years. This talks to the point that before capital is invented, explore all possible alternatives of expenditure before doing so.

4.6.6 Question 6: Operational and maintenance allowances

RK: What are your perceptions of the breakdown of operational and maintenance allowances as described as a means to reduce the various types of risk associated with maintenance and operations? Has anything been omitted?

TE: It is very good. Nothing has been omitted from my point of view.

4.6.7 Question 7: Capacity planning

RK: Is my understanding of capacity planning and the necessary steps to take as part of the process accurate?

TE: Yes, it is and it is well aligned with the slide about capacity investment alternatives we spoke about with various scenarios.

4.6.8 Question 8: Timetable significance

RK: Is the statement that ‘timetables produce information about the performance of the railway network (from the viewpoint of the stakeholders) that aid management in decision-making and performance improvement’, correct to your understanding?

TE: Yes, that makes sense. I like the emphasis on the perspective of the stakeholder!

4.6.9 Question 9: Evaluation techniques

RK: What are your overall impressions of the value model, the House of Quality and the identification of the strengths and weaknesses of each?

TE: It all makes sense from my point of view – Transnet uses a model similar to the house of quality in some of our processes.

4.6.10 Question 10: Stakeholder measures of effectiveness

RK: Would you say that stakeholder measures of effectiveness are complete and adequately quantified?

TE: Yes, I believe they are well researched and well informed.

4.6.11 Question 11: Operational and maintenance risk factors

RK: Do you think the list of operational and maintenance risk factors is sufficient for the purpose of the framework?

TE: Yes, they look adequate and seem to be well informed and well researched.

4.6.12 Question 12: Value of the conceptual framework

RK: I have explained all the different aspects of the conceptual framework I developed as part of this research project and illustrated how customer-related factors and operational and maintenance risk factors are brought together in order to determine an overall risk factor for each timetable variation. This is intended to inform decision-making processes regarding which timetable to operate, or which set of timetables to optimise and refine for operation based on best available data (typically based on historical data and experience of the operators). Does the framework make sense to you and do you think it will be valuable within the Transnet environment?

TE: Yes, it does make sense and it seems very practical! This is useful because it helps Transnet identify which timetable will provide the greatest opportunity to be successful in terms of stakeholder valued outcomes. This is a pragmatic way to ensure that the final timetable that is selected is viable in terms of cost and other important factors.

4.6.13 Question 13: Overall framework completeness

RK: Is there anything else that you feel I should give coverage of in my research?

TE: I believe your work is quite complete in addressing the research problem. I do want to share additional diagrams that you may find useful in tying concepts together. I am a fan of the railway operations author, Dr Felix Schmid and his ability to express railway integration and complexity concepts in a manner that is simple to understand.

The figure below speaks to other considerations the different activities and objects that are to be controlled and monitored as part of the railway system.

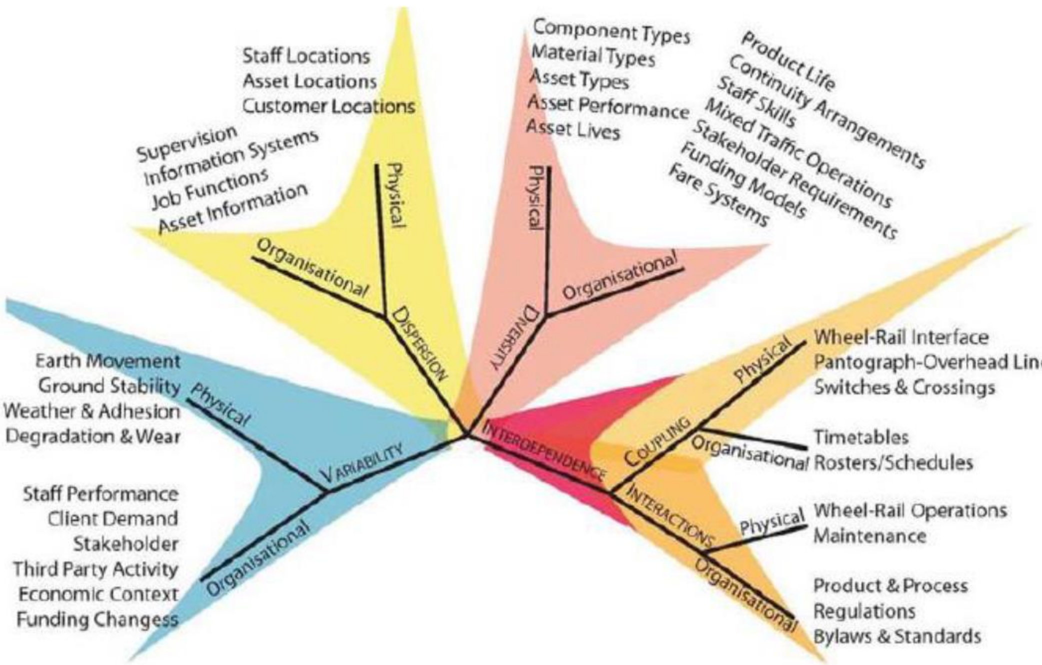


Figure 45: Drivers of railway complexity

Adopted from (137)

The next figure speaks to the subsystems and the interactions between them and different activities within the railway network.

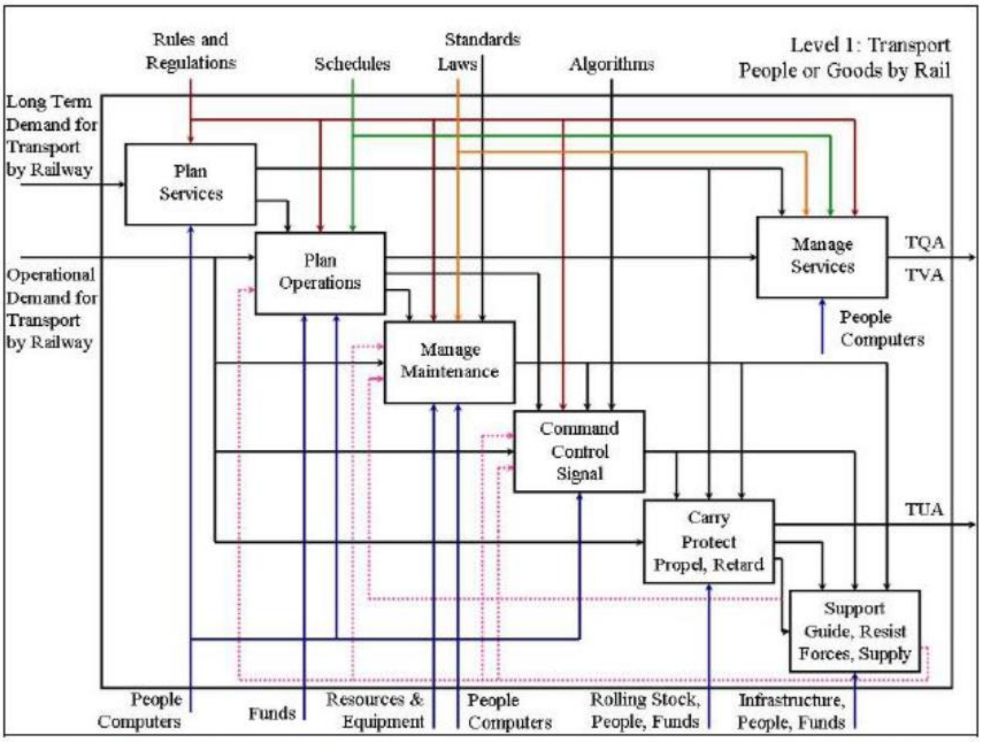


Figure 46: Overview of railway subsystems and their Interactions

(Adopted from (137))

The next figure illustrates the different layers of the infrastructure. As I said earlier, there is a relationship between the level of engineering and level of capacity achieved. Take for instance, the laying of infrastructure. The subsequent maintenance to be conducted on the infrastructure depends in large part on the level of engineering of the track when it is laid. In practice, there should only be maintenance on the two top layers – if maintenance is required from the sub-ballast down, it means that either maintenance of the two top layers was not done correctly or that the initial engineering was sub-par.

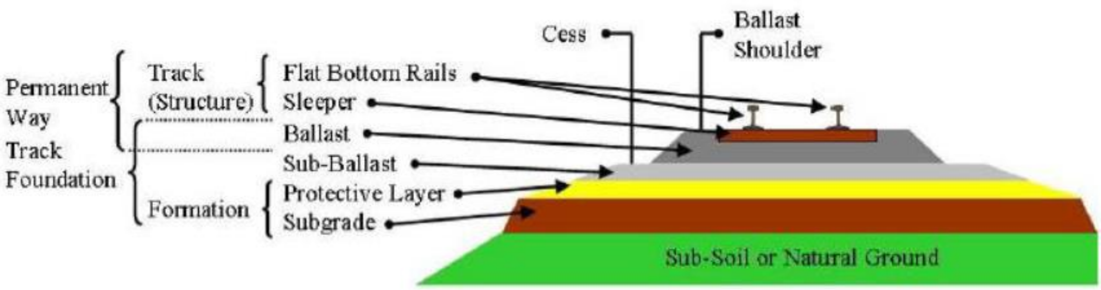
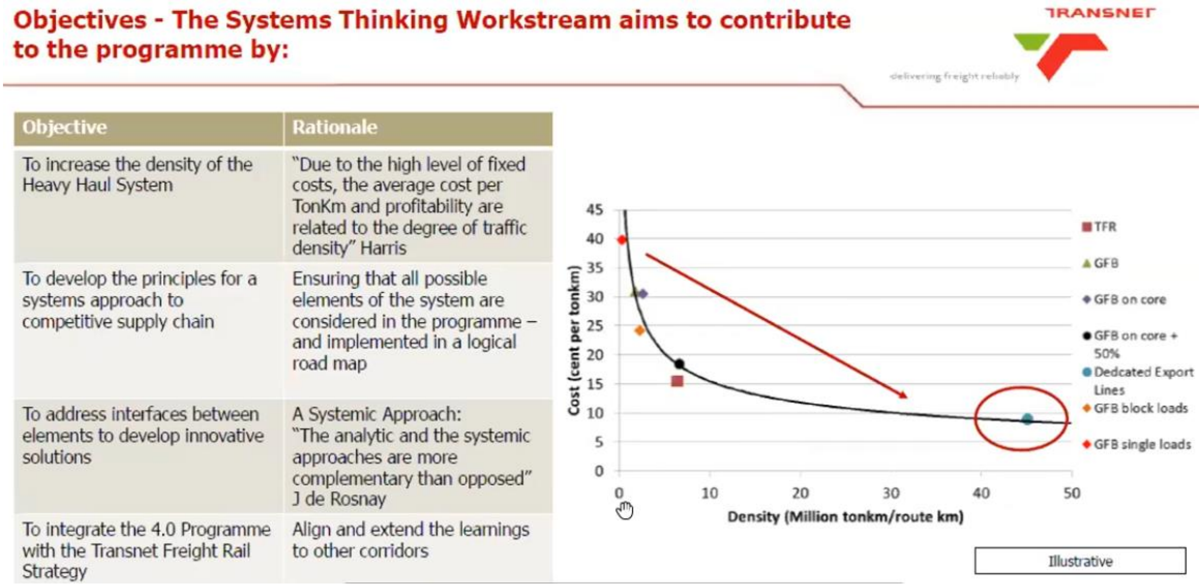


Figure 47: Terminology for structure of conventional ballasted track

(Adopted from (137))

The last bit I want to share with you is regarding capital expenditure early on. The Harris Model that Transnet applies in capacity assessment is promotes transporting large volumes over long distances in order to reduce unit cost as illustrated in the slide below.



Objective	Rationale
To increase the density of the Heavy Haul System	"Due to the high level of fixed costs, the average cost per TonKm and profitability are related to the degree of traffic density" Harris
To develop the principles for a systems approach to competitive supply chain	Ensuring that all possible elements of the system are considered in the programme – and implemented in a logical road map
To address interfaces between elements to develop innovative solutions	A Systemic Approach: "The analytic and the systemic approaches are more complementary than opposed" J de Rosnay
To integrate the 4.0 Programme with the Transnet Freight Rail Strategy	Align and extend the learnings to other corridors

Figure 48: The 'Harris' Model

(Adopted from (137))

Here is a further explanation: the longer the distance, the lower the operating cost but the total cost increases as there is a higher degree of engineering for the infrastructure (higher capital cost). If you spend a high degree of capital upfront, the cost amortizes within 50 to 100 years but the variable operating cost increases with inflation. For this reason, the higher the initial capital cost, the lower the overall cost with time so one can upgrade and refurbish without pricing oneself out of the market. However, if one favours lower capital costs for high operating costs, the value goes up with inflation which means that total cost will exceed the initial cost with time and one can place themselves out of the market. With this thinking, it makes sense as to why vehicle companies replace their vehicles very frequently. In addition, a lot of railway companies spend capital to restructure the balance sheet. However, the fact remains that capacity is achieved by exploiting existing infrastructure. If capital is spent, it should always be done in order to reduce risk! In general, risk can be mitigated by:

a) Investing additional capital or resources to minimize it
b) Financing risk through insurance however this is expensive as it is an operating cost (and so increases with time)
c) Engineer it out through application to assets, infrastructure or operational mechanisms

In this case, option a) and option c) are far better options. Your research addresses option c) very well.

5 DISCUSSION

This section serves to explore the meaning, importance and relevance of the results contained in Section 4. For simplicity in referencing, the material has been organized according to the order in which the results are presented in Section 4 – Results.

5.1 Results from 'Mapping the Selected Data Sources'

This initial phase of developing the conceptual framework comprised of an exploratory focus group aimed at identifying challenges to operations. It also comprised of a second discovery activity aimed at identification of data sources for the literature review and conceptual framework.

The focus group identified 5 main classes of challenges to operations leading to cancelled, delayed and staged trains namely: safety, technical, environmental, crew, operations and customer-related issues. This information would form a major input to the operational challenges that should be budgeted for in allocation of operational allowance.

When analyzing the entire set of contributors, it is evident that the factors may be attributed to issues internal to the system of interest (SOI), issues external to the SOI or a combination of the two. Here, the 'SOI' comprises anything that plays a role in the transportation of freight that Transnet owns, as these are the factors that are within Transnet's control (see Figure 9: The 'Poached Egg' diagram for more detail on the SOI and its environment). Example factors falling into each of these three categories: internal to SOI, external to SOI and shared between internal and external include:

a) Internal system factors – design incompatibility with operations
b) External system factors – no freight for train (due to customer-related delays)
c) Shared responsibility factors – network unavailability due to theft

A significant portion of the set of factors contributing to cancelled, staged and delayed trains fall into type a) and type b) above. This is indicative of potential organizational deficiencies that may contribute to improper planning and execution. The significance of this was in the latter part of the research process and is discussed in Section 5.5.

Other factors contributing to cancelled, staged and delayed trains were identified as shown in Figure 23. These factors reinforced the necessity of a systems approach to addressing the research problem, i.e. 'no overall view of the system and incompetent decision making'. These factors also reinforced the notion that there are potential challenges at the organizational level e.g. no single point of accountability.

Overall, the brainstorming session provided invaluable access to terminology that would be used in the process of developing driving questions in search of relevant literature to address the research problem. Deriving driving research questions that expand on the primary research questions and then finding appropriate literature for each of these driving questions was an essential step in developing the conceptual framework.

5.2 Results from 'Extensive Reading and Categorizing of the Selected Data'

This activity revealed the vastness of the railway capacity subject matter. Views on railway capacity differ from the passenger sector to the freight sector, from country to country and from railway company to railway company. The landscape of literature on railway capacity posed quite a challenge to create a congruent model on operational capacity when the terminology regarding capacity and areas of focus for various authors were so different. The mind map in Figure 24 shows an organized layout of the main concepts that emerged from the literature review. Concepts were selected for organization and further research if they met one or more of the following criteria:

1) high level of importance placed on the concept in one or more pieces of literature
2) high degree of repetition of concepts across multiple pieces of literature
3) ability of the concept to contribute to understanding of operational capacity in a substantial way

If the above criteria were met, the concept was associated with a higher-level concept. This approach proved to be effective for assimilating the data and increasing richness of understanding.

This phase of in-depth research also led to the discovery of pivotal statements which were paramount in formulating the proposition of the research which is that:

1) evaluating timetables is a suitable alternative to evaluating operational capacity,
2) timetable evaluation should be based on stakeholder-valued outcomes
3) operational and maintenances allowances are afforded in order to reduce the risk of not meeting stakeholder values and objectives

The most significant statements discovered are reiterated below (mention initially in Section 2 – Literature Review):

- Canace et al: Timetables represent the step from planning with most influence on the user's perception about quality of the service and thus timetables are a good reference point for capacity evaluation (87)
- Brebbia et al.: Timetable analysis has proven to be efficient for capacity evaluation (76)
- Lidén: Increasing the size of the allowances increases the reliability of the timetable by acting as a buffer but also increases the travel time – an important timetable quality criterion (70)

The above discoveries were pivotal to the formulation of the conceptual framework.

5.3 Results from 'Integration of Concepts'

This activity integrated the concepts from Phase 2 of the research methodology above into a framework with increased connectivity between the various concepts. In a way, this integration map from Figure 25 posits as a meta-framework illustrating how the various concepts relate to each other on a sequential basis. The map is based on the infrastructure and timetable construction diagram in Figure 14 adopted from (88). Figure 25 also integrates capacity delineations according to Transnet's framework (theoretical, operational, practical and used capacity), capacity planning stages and activities, and important systems engineering activities including:

- establishing requirements
- making decisions based on stakeholder values and requirements and
- constructing, operating and maintaining based on those requirements.

As described in Section 5.2, the proposition of the research revolves around evaluating timetables as a mechanism for evaluating operational capacity. Upon further study of the resulting mind map in Figure 25, it was evident that the application of this framework would be most valuable during the tactical planning phase when timetable alternatives are formulated for eventual evaluation and selection.

5.4 Results from ‘Synthesis, Re-synthesis – Making it All Make Sense’

This section comprised of the activity of constructing the conceptual framework and researching critical aspects required for application of the framework. The basic premise behind the conceptual framework is that by hybridizing the Value Model and the House of Quality to include the impact of operational and maintenance risk into evaluating timetables, an evaluation of operational capacity true to its definition could be realised. It also allowed for minimizing the weaknesses and maximising the strengths of each of the evaluation models popular in systems engineering. The framework outputs information regarding the level of risk associated with operating each timetable version. This enables selection of a timetable based on its ability to meet stakeholder objectives, rather than on developing and operating a timetable on the presumption that operational capacity is 65% of theoretical capacity. This may enable operational and capacity-related execution to be more aligned with operational and capacity-related planning. The details regarding formulation of the conceptual framework may be found in Section 4.5.

The ‘system effectiveness model’ portion of the framework was based off of realistic figures as discovered through research. However, the population of the framework in terms of relationships between timetable metrics and operational and maintenance risk and timetable alternatives were based off of fictitious data to demonstrate the logic of the framework. In this case, application of real-world examples to the framework would require getting access to information from Transnet not necessarily available in the public domain. This would require additional resources and processes to be adhered to that were deemed out of scope for this 50/50 research project. The lack of validation at this level is a limitation of the research project and provides prospect for future research to assess the validity of the framework). One measure that counteracted the lack of validation achieved from real-world application which was the interview conducted with a Transnet employee and subject matter expert (on operations and capacity). This Transnet employee who answered detailed questions regarding the framework and the supporting research behind it. The takeaway from this interview are discussed in Section 5.5.

Another limitation of the application of the conceptual framework as presented in Section 4.5 is that the risk associated with each estimation has been largely omitted. Incorporating risk into the model increases its reliability by accounting for the uncertainty in the model. This can be done through Monte Carlo analysis or other suitable method to produce a set of probability distribution functions, instead of a fixed number for any cell requiring a numerical input. This would also require advanced statistical computing software and a fair degree of knowledge about statistics by modelers. There is a balance to be struck between accuracy and ease-of-use as the conceptual framework is evolved. The more sophisticated the calculation becomes, the more accurate it may be but also the challenging it is to apply and the more computation power is needed to conduct the calculation. The level of sophistication required will depend on the risk associated with its application. If the framework will be used to select three timetables to take forward into a more detailed analysis, it may be suitable as is. If, however, the conceptual framework was going to be used to select the final timetable to run, a greater degree of certainty may be required and this is achieved by a more sophisticated form of the current model.

It is worth noting a systems engineering principle that the greatest utility in evaluation is not from the numerical result of the calculation associated with each alternative but from the results emerging from the comparison and the insight gained from the evaluation (26).

In application of the framework, it is advised to adhere to the following principles for the best results (135) (72):

- Corroborate data used in developing weights
- Weigh the influence on decision-making for different stakeholders
- Re-weigh the value for different uses (different networks, different sets of assets, different stakeholders each require a unique population framework data for application of the framework to be valuable)

It is important to note that the results of the framework are only as valuable as the quality of the data used to populate it. The framework should be populated based on experience, access to historical data even additional modelling and simulation information.

5.5 Results from ‘Validating the Conceptual Framework’

This section interprets the results from the interview conducted to validate the research leading up to the development of the content of the final conceptual framework. For the summary of the discussion, please see Section 4.6. For the extended interview, please read Appendix C: Transcription of Interview.

During the interview the Transnet Employee (TE) indicated that there were several aspects that were strong regarding the research content and derivation of the framework:

- The definition of capacity as comprising acceptable services levels and costs, present and projected demand, schedule and operating plans, defined thresholds and variability on the basis of conditions was deemed reasonable
- The definition of stakeholders as illustrated in Figure 10 and the corresponding roles that stakeholders play in determining timetable evaluation metrics was deemed to be valuable particularly as Transnet is seen as an ‘interconnected. The TE confirmed that Transnet is owner-operator in the freight rail business but that it will be expanding its role and eventually even compete with its customer in consolidation activity in future. Thus, the various stakeholder perspectives are valuable as Transnet may have different interests when viewing railway operations from a different perspective and these interests should be moderated and aligned.
- The perception of allowances as a measure taken to reduce operational and maintenance risk was deemed suitable
- The capacity planning steps were stated as being suitable to the needs of Transnet
- The proposition of using timetable evaluation to evaluate operational capacity was stated as being pragmatic and sensible
- The overall framework was stated as being pragmatic and sensible

There were a handful of points that were given to reinforce and expand on concepts within the framework in order to improve its accuracy and utility. When discussing the location capacity type, it was iterated that network capacity revolves around the idea of velocity rather than speed and removing idle time is often a more cost-effective approach to increasing network capacity. This relies on maximizing volume over distance transported and maximizing the capacity of the yards. For a single track, the distance between loops and headway between trains is of significance to capacity. The impact of this critique is that it provides potential timetable evaluation metrics i.e. train velocity, yard processing rate and average distance between passing loops.

The above feedback on considering velocity as a network capacity was reverberated when discussing timetable evaluation metrics. In addition, for the level of service metric, the concept of OTIF (on-time-in-full) was suggested. This too could be a crucial timetable evaluation metric introduced into the model.

Even though the reason for challenging the 65% rule as a basis for determining operational capacity was accepted, the effectiveness of the framework in application was stated to be dependable on three things: the level and standard of engineering, the level and standard of maintenance and the level and standard of predictive technologies. This was supported by the fact that high operational capacities were achieved on the ore line as a result of it having a closed network which makes very frequent, regular preventative maintenance easy to carry out. Here the level of engineering and maintenance enables a higher-than-typical operational capacity.

Another topic of discussion was the potential impact of introducing enhanced wagon technology (e.g. air brakes), distributed power, enhance locomotive technologies (e.g. dual voltage locos) on capacity. TE suggested that capital investments may offer a fantastic result regarding capacity creation, if the necessary trade-offs are conducted prior to investing and the investment offering the highest opportunity is made. An issue with Transnet regarding capital investment in the past has been the lack of structure in the decision-making process and lack of reliable information regarding the need to be met. To account for these potential technology enhancements, the conceptual framework presented in Figure 28 may be adapted for use in evaluating between technological alternatives by adding these features to the set of 'controlled factors'. This way, instead of evaluating different timetables to determine which timetable posed the lowest operational risk, the framework would be applied to different technological solutions to determine the lowest risk technological solution to invest in, with respect to stakeholder values. The key message from the interview for this segment was that: capacity creation is best achieved through a combination of operational and maintenance improvement and measured capital investment.

To enhance the proposition that capital investment has positive consequences, TE spoke through the slide shown in Figure 48 - The Harris Model. According to TE, the Harris Model is used to calculate the projected life cycle costs of an investment. The application of the Harris Model reveals that if the capital investment is low but the operating costs are high this may lead to higher-than-expected life cycle costs since operating costs continue to grow with time due to inflation. For a high initial capital investment and lower operational cost, the capital investment amortizes over the years and a lower operational cost will increase proportionately so that the overall lifecycle cost may be lower for the latter case. Having higher life cycle costs leads to a higher charge (price) for freight services which may reduce Transnet's competitiveness in the market i.e. Transnet may 'price itself out of the market' which negatively impacts on its business position. This discussion point showed that there are instances where capacity investment is beneficial, specifically when the need is well-understood (in the form of clear requirements) and when a structured trade-off is conducted to determine the best alternative. The process of capturing and analysing high quality requirements (a systems engineering activity) is outside of the scope of this project but would be an essential activity in deciding how to invest capital.

5.6 Rethinking the Conceptual Framework

The conceptual framework developed will serve the purpose of informing decision making within the tactical planning phase of capacity planning. Emerging from the validation step of the research methodology, there are two improvements to the framework that could be made for an enhanced framework:

- Including train velocity, yard processing rate, average distance between passing loops and probability of on-time-in-full (OTIF) delivery in the timetable evaluation criteria to account for important measures within the network from Transnet's perspective would enhance the utility of the framework

- Including various wagon technologies, locomotive technologies and average length of passing loops as controlled factors (to be used or not used as desired) to enable evaluation of technological solutions. This would essentially entail evaluation of theoretical capacity since operational capacity presumes fixed infrastructure and assets (16)..

In a number of the figures shown by TE, the impact of the organizational model and capability became increasingly apparent. This is affirmed by:

1) Figure 43 affirms that 'organization culture' is a significant contributor to capacity
2) Figure 44 describes costs, people, assets and safety as components of overall efficiency and; rolling stock, infrastructure, systems and technology as requiring capital. Balancing these dimensions requires organizational processes and policies.
3) Figure 45 indicates that there is a physical and organizational aspect to the four drivers of railway complexity: variability, dispersion, diversity and interdependence (coupling and interactions). This requires a high degree of organizational competence to manage.
4) Figure 46 shows that there are a multitude of interacting activities and services within the railway network that require organizational control to manage (i.e.: planning, managing, carrying out and supporting services of the railway)

As with applying a structured methodology to evaluating operational capacity, so can organizational maturity be evaluated and assessed over time. An Organizational Maturity Model (OMM) is a collection of reliable, proven processes forged into a five-step framework that provides a roadmap for organizational improvement (138). The most popular OMM is the Capability Maturity Model (CMM) by Carnegie Mellon's Software Engineering Institute (139).

The five generic stages of any OMM are as follows (138):

1. Informal – processes that are ad hoc, initial, chaotic and inconsistent
2. Documented – processes that are emerging, managed, standardized, isolated and repeatable
3. Integrated – process that are defined, structured, measured, competent
4. Strategic – processes that are aligned, disciplined, predictable, quantitatively managed
5. Optimized – processes that are adaptive, opportunistic, synthesized, proactive and agile

Bueno Alencar set out to assess the OMM of three logistics service providers according to the Supply Chain Capability Maturity Model – $S(CM)^2$. The $S(CM)^2$ model assess level of: documentation, standardization, strategic and technological integration, service level agreements, measurement and analysis of the of performance of the service level, certification and many others (140). The conclusion of the research was that there is a relationship between the size of the organization and the level of maturity where a small, state-controlled company had the worst level of maturity while the best overall company was the largest company. The research also showed a disparity in the ratings for each of the processes versus ratings as a whole.

It may serve Transnet well to assess its current organizational maturity and develop a road map to take Transnet from where it is to where it wants to be. Conceptual frameworks like the one that forms part of this research may be valuable in elevating its position. Even if Transnet did not elect to align with an established framework like the $S(CM)^2$ or CMMI, Transnet may develop its own internal capability model. One possible consideration for this effort is to develop a ‘Capacity Creation Capability Model’ that considers all the elements of Figure 44 including costs, people, asset and safety (as components contributing to efficiency) and rolling stock, infrastructure, systems and technology as components requiring capital for further investment. Such a maturity model could outline stages based on Transnet’s could encourage using feedback from application of this conceptual framework to improve Transnet’s alignment of capacity execution with capacity planning.

6 CONCLUSION AND FURTHER WORK

Transnet has recognized the need to closely align capacity to demand to address the capacity problem. In order to do so, Transnet needs to maintain favourable practical capacity utilisation levels. Operational capacity is an important consideration in practical capacity utilisation as capacity utilisation is *used capacity* as a percentage of *operational capacity*. Transnet has historically adopted operational capacity to be 65% of theoretical capacity despite seeing rail lines within their network performing at close to 80% operational capacity. This research proposes that operational capacity may be evaluated by evaluating timetables against stakeholder-valued criteria.

The conceptual framework developed as the main output of this project is a hybrid of the Value Model and the House of Quality systems engineering evaluation tools which maximizes the strengths and minimizes the weaknesses of each of these models alone. The output of this framework provides insight into which timetable within a set of timetable alternatives poses the least risk (or greatest opportunity) to meeting stakeholder-valued outcomes. This will increase the perception of performance of the railway network by stakeholders, as well as open the door for networks to exceed operational capacity levels of 65% since that constraint is lifted when developing timetables.

In order to address the research problem, four research objectives were devised:

1) Establish a detailed definition of operational capacity and distinguish from the other types of capacity
2) Identify the elements comprising operational capacity
3) Develop a conceptual framework that illustrates the relationship between the elements comprising operational capacity
4) Validate the developed conceptual framework through engagement with industry experts such as managers, engineers, operators etc.

Through the application of a structured methodology, including validation through a one-on-one interview with a Transnet subject matter expert, the research objectives were met and the value and pragmatism of the framework was asserted. The systems engineering approach proved to be useful in analysing and addressing this complex problem and while the value of the application of the framework has not been validated in the real-world, there is sufficient evidence to encourage further research on this framework. Further work to validate this framework through application of the model to real-life timetables is advised for the future.

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Appendices

Appendix A: Case Studies of SE Application in Railway Projects

1. *UK West Coast Route Modernisation Project*

Between 1998 and 2008, the West Cost Modernisation project carried out a substantial amount of work to increase capacity and reduce journey times in the UK. By 2001, the project had risen in cost from £2.5 billion to £14.5 billion when only one sixth of the scope had been delivered. In 2002, the Secretary of State enlisted the Strategic Rail Authority (SRA) to intervene and develop a new approach to completing the project who then clarified the direction, scope and expected outputs of the project. These steps are typical of the systems engineering approach as illustrated by phase 1 and phase 2 of Hall's description (above). Other issues identified included lack of project governance and lack of communication with relevant stakeholders. The UK National Audit Office (NAO) compiled a report and concluded that the SRA had managed to gain possession of the track in order to conduct more extensive engineering work and the program cost was lowered by over £4 billion. The NAO concluded that adoption of sound SE practices led to significant reductions in cost and timescales and that had SE been adopted earlier on, further savings would have been afforded.

2. The Skytrain Control Centre Upgrade and Expansion

The Vancouver SkyTrain is a fully-automated light rapid transport system that underwent major expansion from 1999 to 2002. During this time the control centre that carries out all of the control of the trains was relocated to a temporary control centre that was required to allow for business-as-usual operation and seamless transition from the old centre and back to the upgraded centre.

The challenge was that initially, it was only expected that modifications were required but as time unfolded, it turned out that much of the equipment was obsolete. A thorough systems engineering approach was conducted including detailed requirement analysis, risk analysis and management planning and system configuration management which revealed that ergonomics, equipment and interfaces were an important consideration in design. Detailed testing and verification plans were developed so that minimal interface-level testing had to be conducted when the facilities were ready to go live. The project was highly successful as a result of considerable planning, risk analysis and configuration management. Although requirements were not clearly understood in the beginning, good application of Systems Engineering revealed necessary considerations and supported the successful outcome of the project.

3. *Jubilee Line Extension*

The Jubilee Line Extension Project (JLEP) was initiated in 1993 with the objective of extending by 16km through two busy terminals. The project was estimated to have a benefit to cost ratio of 1.75 but was almost 20 months over schedule and £1.4 billion over budget. Issues identified included poor project management and the unexpected financial collapse of a participating investor the physical collapse of a tunnel bored by another project which delayed construction. Mitchell writes that if a whole systems view was adopted, the holistic implications of the extension beyond that of a ‘bolt-on’ of the Jubilee line would have been considered as necessary (141). Mitchell quotes the General Manager of the Jubilee and East London lines as stating that it was not until late in the project that it was considered as more than a construction project but as a project involving people, systems and assets to be brought into an operational business. Although the JLEP was a successful project in terms of improving London’s transport infrastructure, authoritative accounts describe that if SE was practiced well form the outset, many of the issues created as a result of not considering the whole system would have not occurred.

Appendix B: Letter of Invitation for Interview

Dear sir/madam,

My name is René King and I am a Master’s student at Wits University. I am currently conducting a research project titled, ‘Development of a Conceptual Framework for the Evaluation and Analysis of Operational Capacity for a Freight Railway Network’. I am contacting you because of your role and experience in freight railway operations at Transnet. Transnet is the sponsor of my research and thus the conceptual framework above has been devised with Transnet’s General Freight Business as the subject of the framework. I believe you have key insights into important aspects related to the framework and I would appreciate your constructive criticism of the framework to improve its reliability and validity by way of a one-one-one interview.

For this 2-hour interview I will assemble a set of key questions to guide our discussion in which I seek critique on the work I have conducted as part of a validation activity. You need not have any prior knowledge of the content as I will be explaining the content and structure of the framework during the interview. The goal of the interview is to receive feedback on the coverages of topics for the research project, the proposition of my research and the conceptual framework and its details.

With your permission, I would like to audio-record the session to ensure that I accurately capture your thoughts and suggestions. Your participation in this session is in no way compulsory and your identity will be kept anonymous in data capturing and in reporting in my research report. Only matters concerning your professional opinion and expertise on the subject matter will be raised. There are no known risks to participating in this study.

If you have any questions or concerns please do not hesitate to contact myself of my supervisor, Nicholas Cloete-Hopkins for more information.

Nicholas Cloete-Hopkins

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René King

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Sincerely,

René King – BSc Mech(Eng)

School of Mechanical, Aeronautical and Industrial Engineering

University of Witwatersrand

Appendix C: Transcription of Interview

TE
Hey! Good Morning. Sorry for late.

RK

I'm sorry I got the time wrong the entire time I was thinking 8:30. 8:30 your times 5:30 my time this whole time that's what I thought so I'm sorry about that I think I'd sent you an inch and here it's a million right but they weren't the same

TE

I was looking at your document one day when I learned how to write well I want to be able to write like you

RK

okay how about we swap I'll do the right thing and then you can just have all the knowledge on operational capacity and everything because it's been a road just trying to get to this point of understanding

TE

I've looked at your profile I think on LinkedIn so the stuff should be easy for you this is the stuff that you've already

RK

Wow let's say that me what and I'm working with PPI is a very structured approach to solving problems but I'm the tough part about doing case studies on transience is that a lot of the information there's not that much online that's been related to exactly what I've been trying to do so a lot of it has been taking the context of what is spoken about in overseas papers and having to kind of like work it back but provide a structured link so how it can be applied for transit so that's what's been very tough I haven't liked being able to just search your documents and like this is exactly what I'm looking for and which is why it's taken some time to get your and also wide this segment of the research is so important is having somebody is that feedback who's working with the stuff and knows like the terminology and how it's broken down

TE

I fully understand I am currently studying as well and I can relate to what you say translate has not certainly not in the last 10 to 15 years published too many documents but there they are some that's available one of the sources that I rely on for my studies is a former engineer that worked here his name is dr. Dave on demeanor and he's currently part of the team that's working with Department of Transport and they've recently published the draft white paper on national rail policy

RK

Okay

TE

he works with research group it has several former sports net and transmit engineers all over the world and they kind of collate the information that they publish and put it on a site that he manages I just want to see if I couldn't get the name of the site for you quickly

RK

so great and would you be open to tell me about your topic as well if you have a few okay I'm so curious

TE

yeah we could chat about that I see it's called railway corporate strategy is easy

RK

okay

TE

if you just google his name dr. Dave on demeanor it takes you straight to East Side and then you'll see that this is quite a few documents that easy the author little call was it that a published a which gives give some useful insights to south African perspectives I think another district would be the professor University of Stellenbosch after neither these work quite a bit and there's another gentleman yoke funder Marimba who is also former scorn and you this is published a few documents but in the last two or three years we've started to see more and more documents published by translate stoppages which are encouraging one of the materials you'll find is maybe six to ten years old

RK

okay well that's good what a relief rise that as you're doing your research more things are coming in I'm hoping to be submitting like next month on this topic so hopefully, I can wrap up I need to just finish my comment my discussion in conclusion but you know the outcome of this meeting is not to say like everything you've done is perfect great you can continue any feedback is good I've got sufficient support for what I've done so far but then it's a critical part of discussing like where the shortcomings on and so I think what could be a good approach maybe if I walk you through my research document just like kind of gently touching on how I've got to this point and then I'll go into the conceptual framework which is an Excel spreadsheet and then we'll be able to like pick apart it's a little bit more detail but just so I'm aware what time do you have to be off I think that you might be a little bit busier than me since it's your the beginning of your day and the end of mine so just let me know what you mindful

TE

I think we should you order Tolkien so that's fine

RK

okay perfect thank you so ten for you

TE

just one disclaimer I'm not an engineer I'm just an array operation and it's happened to be here for a while so

RK

that is perfect don't even worry the engineering side that sees this topic of mine it's conceptual right so I probably already as it is going too deep in some ways but yeah the whole point is that it's conceptual we're not getting into the detail design no this is not what the objects of this I mean so you're all too fast because people sometimes

TE

I make them dizzy but I'm just like right here the documents so I'll just be growing up as follows this IKEA knowledge you know

RK

okay so I'll just kind of talk to each of the sections

TE

I miss Paul Susan house name

RK

its tau like that yeah perfect thank you so I start the document by speaking about I'm the capacity problem which is you know a growing need for a growing demand but not necessarily the resources to be able to match that and that typically there was an infrastructure or asset-based approach where it's like okay we need more capacity will build more will buy more and now that becomes expensive after a while and also they are long time frames and that is required to do that so yeah I'll just talk through it and then you can stop me at any time if you think what I'm saying

TE

no problem

RK

is something like that okay cool so then I dive straight into so there's just the foundation is that you know understanding capacity is a worthwhile investment of energy seeing as relying purely on purchasing trains and building new tracks is not always going to be the best routes to all problems so then I break down my understanding are

TE

it just might be a bit of detail but transmit is not just railways so the capacity you're defining your Israel capacity I would imagine if you're talking about the port business of the pipeline's business in the definition of chemistry would be somewhat different

RK

right

TE

so I've just made of this first portion down to capacity

RK

hmm so true very so like we're talking like the TFR environment and which I need to I'll probably clarify that in my in my abstracts a little bit more because it's the CERN but that's hundred-percent I've noted it yeah so then we're jumping into the three different kinds of capacity well yes I'll just subscribe it from my understanding so theoretical capacity is what in a perfect world would be able to be achieved our rational capacity says okay they will obviously be a need for maintenance and there will be operational aspects such as the fact that you're goanna have a delay sometimes but the things that can be preempted the difference between operational and practical is that practical relies on the condition of the track at that point in time operational relies more on the operational and maintenance challenges that we can forecast and then account for those risks by budgeting in some time which so typically they would say that operational capacity is about 65% of theoretical capacity is the rule of thumb that's taken and then compare price book capacity will be a subset of that and then use capacity well I guess the aim is to have that as high as practical capacity but that all depends on demand so yeah this charts I mean this chart says it all and I'm focusing on just that bar so you know okay and then I talked about the component of utilization and basically how demand can never be completely separated from capacity as a general consideration okay then what I started noticing from the research that I did was that operational capacity is not really used in a in a global sense often they use the term well actually there's a couple of authors see we transit users practical capacity to be the condition-based capacity if you want if you want to put it that way whereas Aril it's all who comes up a lot as in research and maybe you've seen - if you're doing similar topic - I am and then he comes up a lot is done a lot of research on freight railway capacity you're on passenger capacity a lot of things in rail and the term that he uses is practical capacity so in this section I basically drop the fact that terminology will not like you know be a stumbling block in this research and that the way that he defines practical capacity is synonymous to operational and he uses different terms like available and used to kind of be the you know the equivalent to practical and used in the translates environment so just that practical thing is equivalent to operational just different terminology okay thank you and now I just have some just a brief introduction of systems engineering and how it's been applied in railway projects previously and are you do you interact much with the TCS see the transience of systems engineering you have exposure to systems engineering

TE

and in fact, I was part of negotiating their contract when events

RK

how many years ago

TE

is that three or four years ago. three years ago 2017 ago

RK

okay so they must have been a renegotiation then because I think I started engaging with them a little bit before that and then like with increasing involvement but then ever since I've had this job I just haven't had much time in South Africa never mind adverts so yeah now we've got okay yeah so the application this section is just providing some this disc society in cozy have you heard of them

TE

yeah

RK

yeah so they have they have good papers on systems engineering and the results of its application in the transport environment with the rail they actually have a document specific to transport environments of which the bulk is real oriented which is great so here I just get into like you know some of that the case studies but I have the actual content in the appendix this is just a summary brief summary to just say it's being applied with success and now okay breaking down into the research Christians and objectives after noting the problem which is basically trying to match demand to the supply but noting that high time intensive investment intensive options are not necessarily favorable so now they've quit the research questions on what are the empirical building blocks that need to be considered when understanding and evaluating operational capacity and I'll be talking about it a little bit just now but I've kind of like went into what understanding and what evaluating is even though obviously common English words but I'll break that around to the next section and then what are the relationships between parameters within those building blocks a little bit about the research objective so getting a definition defining the elements that contribute towards it developing a conceptual framework looking at the causal relationships between the elements and validating the conceptual framework through engagement with people such as yourself just a word so whatever this is my I've been working on this document I will tell you how many iterations we would have done so many it's been a challenging road but all of this I still need to go into like a once through from the beginning to just further intensify the story from beginning to end so I'm happy with where I am at the now some of the wording as I'm reading it I would say that's it's not hundred percent suitable to once actually become but it's all there so strong alignment from the proposal to the results it's just that you know and you can improve wording to to improve the golden thread that's what I what I will be doing once I have my discussion is the ones through of everything please don't worry about this diagram this is just me including it to show what I want to do once I've done the whole research report I'll be doing something like this to show how it flows that's all that is okay then the research methodology is this third section which I have to refine and then just summarize it yeah okay so then in chapter 2 which was the main beef of it the literature review so I speak about conceptual frameworks and the different forms that it can take basically a conceptual framework it shows it cons it's it needs to convey a certain level of simplicity and a concept by sharing relationships so normally what happens is that a conceptual framework is used and this is the part that was challenging for me in the beginning of my research is because I was conducting my research on a search on goggle phrase by phrase places and being very confused are not finding the answers that I want to when I realize you have to take a lot of initiative in your own work and adapt creativity and you know synthesize as you need you so normally what would happen is you'd have you do initial research on a topic and then you would come up with a conceptual framework to help you address the topic and then you'd kind of dive into the research after that and then that would you know that's normally how it goes in this case it's something a little bit different the conceptual framework is the product not a means to in the end and that's just coming up with a pitch a conceptual framework is what it is but conceptual meaning not detailed design at a very high level yeah understanding of it with clear way to improve it in the future that's what the objectives are so we've got the research issue which we discuss the research questions the research design and conducts which would be a combination of initial research getting feedback from it and they which I've already done one focus group and I got some results from that and then this s this part is kind of like the second the second review of it and then I'll be doing finalizing the framework so then I developed the initial one now we're in this phase and then I'm goanna be refining it and then just coming up with some conclusions okay so understanding I think that's the part that's a little bit more intuitive evaluation is the one that I found very interesting evaluation in terms of engineering has to do with more about finding information to help you reach a decision so yes it's evaluating in terms of numerically defining but it's also in terms of creatively coming up with some let's say designs in general and engineering terms you'd come up with some designs you analyze the designs and then you'd evaluate or compare is a synonym in this case to pick something that is the best for your situation but there's always that for the purpose of decision making component to it which was yeah a little bit of a turning point in the direction that direction of my research was clarifying that so now this basically just talks about the main objectives of the conceptual framework so you want is something that explains that links empirical findings that captures relationships that highlights analogies incorporates insights and enables comparison and selection so that's just bringing it also give it to say what I'm going to try to achieve with this framework then what I've got in the next section and please don't judge the format

TE

I like this that is very useful for me

RK

you are you know to be honest with you okay this is literally my third time doing this whole research report not even third I think it's my fault and I mean from start to finish completely new approach completely new thing it's just been trying to get that golden thread is what I've been fighting with for a long time and I found that breaking up into components what the expectations of the product is helped me to see okay cool if I do it in separate phases or if I bring it all together if I can check the boxes of explanation linking findings capturing relationship hiring well I mean highlighting that then I'm done and that was like you know from there it was just about before that so tough so yeah I can definitely provide blood certain cheese's input to that that activity okay so think what I've done here is I took the research objective in one column the conceptual framework aspects from this list that would be addressing the research objective and then we're in this research reports that synergy is done I mean that's always the person markings interest but the TS we've got that and then I go into the capacity the definition there is a couple but I kind of just highlighted the ones that came about the most frequently in a couple of you know during a literature review I had like a whole mapping process of seeing the definitions and the amounts of sounds they were referenced this is the these are the definitions that came up the most frequently this part the parts that were most significant which I think I actually speak about here I need to see I think I might remove this and I'm sure you familiar with the UIC and how they kind of calculate capacity but it's interesting but it's this is actually not so relevant to what I'm doing so I'm just goanna for my case just put a comment yeah it's it just it's running from the flow if you know what I'm saying

TE

so I'll just literally before you remove it put your comment I'll come back to that just now I find for my purposes I mind this particular description quite useful

RK

okay cool I would be really keen to hear that so I'll just say come back here as a comment okay so yep just it made sense to me which is why I included it but in terms of my particular topic it seems to be a little bit of an outlier amongst all of this research so now I basically summarized let's see if it's yeah these are the aspects from all the definitions that came apart across quite strongly was that it has to do with acceptable levels of service on costs so it's not only about being able to physically move it but are you being able to remove it within an acceptable level of performance you know things like delays they become an unacceptable after a while in demand schedule and operating plans to find thresholds and variability of conditions so those are just terms that I pulled up from the hundreds of definitions that we're important okay now like I said the section I don't know how really fits anybody much in types of capacity it turns out that there's one way which is again by Aubrey little and there are more references yeah but he kind of broke down this way of how capacity can be viewed on a location basis a calculation method basis and degree of utilization basis so in essence I suppose you school you could mix and match if you wanted to you know to say am I going to be looking at the location method or the utilization but this is just part of my you know the initial literature review so this is a decision that would have to be made I guess at the start of you know coins defining your boundary or your system point six four for calculating capacity so I'm that just provides a basis for knowing what you're looking for beforehand and then okay it's just a graphic images

TE

yep with regards to can I see what you put online capacity at what okay that's quite critical so our primary production unit is this new component the first one volume over distance so you want to move the maximum volume against the edge of the lower the unit cost and you want to move it over the long as possible distance because that's really what you get paid for moving so when you look at the network capacity location becomes a bit tricky because it's very finite in its parameters yet you want to look at it across the network can be ability to flow so the whole notion of velocity is critical to that definition that's the one part of tramway the other part of tramway we have these huge odds whether you call them marshalling yards or shunting yards etc where you bring trains together break them apart decide which direction you want to send them etc and in the yard itself it's how many wagons or how many trains you can process within a specific given time so on the net that way you running its volume over distance in the yard it's the number of units per time so your terminal capacity leans a lot closer to capacity of yards as if you don't have sufficient capacity in the yards you can't feed the network your network capacity definition needs to mean more towards the ability to be consistently movie so it's not about speed it's about eliminating standing time or dwell time as we quality driving you then get what you put online capacity if I yes if you have a single line and it starts and it ends here if you put a train into the system and one in on the other side you create a recipe for a collision in the middle what you didn't do is you passing loop so that one train can go into the loop while the other one passes so that you eliminate the collision the distance between groups then dictates how many trains you'll be able to process in a specific given time where you have a double line and what you start to talk to at the bottom you didn't introduce signaling so that you regulate the amount of time between trains and the reason you do that is so that the trains don't run into the back of each other so your two capacity defining elements will either be the distance between stations or loops the most at dictates how much time will pass before you can initiate the next movement or the head weight between trains where you are able to run more than one train

RK

right okay agreed and that makes a lot of sense and to be honest that's a very clear explanation for material have read in bits and pieces in different places that have been another tough bit of it is like getting a visual of the whole story because a lot of the research papers are the scientific approach looking at a very narrow path simulating in a very unrealistic environment or enemy I mean it serves its purpose but in a mathematical environment and then reaching a conclusion based off of that but it's very like tunnel this is what the product is not that many papers, unlike a practical approach, maybe reading these papers you suggested will help me in this discussion but a lot of it is mathematical environment looking a very specific scenario so that that helps me

TE

and I think the difficulty is to get good peer-reviewed material requires you to have a very strong bias towards hardcore engineering and most of the published papers are published by engineers not commons like me.

RK

no no yeah but it's true and so yeah I'll add that so a lot of what you're telling me now I'm not gonna go back and change my research but what you're telling me now is all fundamental feedbacks that goes into like my discussion my critique of my work so thank you it's all very good keep it coming okay so now we're at the point of okay we have the capacity types and they're improved now with your and add-on it's now matrix, in general, they are three main matrices that people usually use or the research that I found the real estate people so do boots which I guess is on the consideration of what you were saying which is like your volume over distance weight volume over time is a volume over time a volume of existence were you saying

TE

volume of the distance

RK

Yeah then the level of service over time he writes okay cool the level of service would be like for example looking at your delays because delays came up as a is a very common measure of capacity because if you kind of look at like the feedback loop okay we say we can do this but every time we commit to that we're constantly being you know constantly running hours weeks behind whatever it might be kind of hope you know weeks for certain cargo but at certain points which might tell you that they're certain segments of the network or certain node is stressed or something like that so the level of service and then acid utilization which is also you know how much are we using you know I'll be committing to using certain trains too much are we finding we're having to repair certain you know some of our assets too much that's also an aspect of being at close to capacity if you're finding that your assets on not surviving you might have the capacity or in terms of the line or their actual infrastructure but if the assets can't match up that's a problem so these are the three considerations or perspectives usually matrix if you will be based on capacity so you can we spoke about capacity types before then we move on to matrix now yeah

TE

so this is brilliant just in a related item that you could just read a paper to on is the concept of out of on time in full you've pretty much kept it at under level of service human your level of service is real-time and place utility in the railway environment so as far as customers are concerned they want to know that it's on time and it's in full so if I've given you a thousand tons to move I want it in the port by tomorrow I want the entire thousand times there tomorrow, not the first five hundred tons will not just the last one so you're all on time in full metric talks to the level of service throughput like what you've written there the term that is growing in terms of its influence on the thinking in railways is the whole notion of velocity which is about consistently moving through the system to eliminate standing time speed

RK

speed right because you can be moving up and down but if ultimately you're not getting in the direction you need to go is a problem so that's very good okay

TE

if you take it back to the beginning of your document and where you are talking about the alternatives of creating the capacity to capital investment investing for speed in an area is extremely expensive it was the level of engineering is so much higher yes whereas if you just eliminate standing time and you have the movement you get the same output without having to increase the capital investment

RK

yeah that's very good that's very true okay now we get to oh yes so just to bring attention to so when we looked at the different metrics different stakeholders might be interested in different metrics for example you know if you're the operator yourself you might be interested in throughput that means more money if you're a customer you'll be interested in level of service because it effects your business and if you are an owner and in an asset owner you'll be interested in asset utilization because you want them to be well looked after but well used just the right amount so then comes the consideration of the different stakeholders and this was a diagram originally drew drawn by Nick from at the TCSE which I'm using here which is permission so which is the main stakeholders that are involved in general in the South African translates environment you know the governance the technical which is the standards bodies the customers which you know could be I guess anybody really with the cargo that they would want to be shipped operational here is the torn said Chris Ron son is an interesting situation right because they are if I'm not mistaken actually maybe you can clarify are they just the owner operators or do they do like the whole business scheme because I think they were they were speaking I read a document somewhere about showing about the label they want to be to in a few years but I thought that they were already there so they do operations and they only infrastructure and they only assets or not the assets or how does it work

TE

it's one of the above in the main we have two large components one we infrastructure owner which means we own the network a network owner and - two we are and operate on the network so those are the two primary roles but there's a very fast-growing element of offering total integrated logistics services wherein several places we are becoming our customer the business that I head for example attempts to do consolidation so that we can present traffic to the railway given the manner that makes sense to the railroad which is large consignments running over long distances but the railway is not interested in single wagons or small consignments and likes of grain rot, etc came into existence to fulfill that role and we are starting to move in - so in some parts, we compete on customs

RK

wow ok well that's amazing that's good I guess the main thing is just managing resources to be able to achieve that very complex and the deep business model but it is possible right with the right people in the right places and the good processes right process is on a pony - okay cool so yeah then I start to talk about okay so there's Katy and a large number of stakeholders but it turns out that translates is like the systems engineering definition of a complex such system because you've got the high stakes environment uncertainty of the future different perspectives evolving nature of a phase and many ways of actually being able to reduce the problem, for example, we've got that you can buy the assets or you can build infrastructure or you can improve operations there are many ways to do it which by definition makes it a complex system again supporting systems engineering as an approach to solving the problem and now I dive into your operational capacity and now I start to highlight the fact that operational capacity is about consideration considering maintenance and operational allowances from the theoretical capacity so you're deducting the allowances from the capacity but not the condition based allowance so this is this the formula that I kind of use in the subsequent sections

TE

okay you refer to the UIC and you mentioned it right at the beginning but there's a basic rule of thumb that says what is operational or practical in a railway versus is the design or installed capacity is typically a 65% with 25% is reserved for maintenance outages etc so you refer to it I will look for a document but it's it is defined as such by UIC as an international standard

RK

okay cool that's interesting I am so I kiss actually which I mean now is a good point to talk about it so my 65 what I was doing is not necessarily challenging the 65% but saying that because I found certain papers we there say that between 60 and 70 you know is typical but that for me is quite a wide range and in the in the in the train freight environment a 1% increase oh you know capturing 1% 0.1% it can all be a big difference on the bottom line so what I was looking at is what is the what is the pay minimum that we owe that translates would accept and then how to compare between one proposed timetable actually which I'll get you and another timetable to see if it can be exceeded so establishing a minimum maybe 65% is it maybe 60% is it and I know that there are different for example I know the o-line they usually get about 85% of theoretical capacity during operation or somewhere on there and that's probably because it's a closed network as opposed to an open network oh yeah it closed a closed line let's say as opposed to open where you have like many different interfaces with different trains and crossovers and things so that's definitely something to consider and so I know that it can vary quite a bit but just given different operational decisions let's say can you proceed with one method with great evidence that you'll be able to achieve basically high operational capacity that's basically so I'm not challenging the 65% but I'm offering a different perspective of being able to make a prediction about how things will go that make sense

TE

which is brilliant I mean at the end of the day it boils down to a few basic factors one what's the level and standard of Engineering two level instead of maintenance three what's the level and capability of predictive technologies because if you if you put more technology for you to monitor more elements of the network and you move significantly towards preventative maintenance you can you can narrow that gap quite a bit so on the or line we've thrown everything we could possibly get on the line to get the highest level of preventative maintenance going which is why we can reduce that to somewhere between 20 25 percent and we've also designed the scheduled to have dedicated fixed maintenance slots so the overall system is actually quite a simple one we want to run six trains put an erection in per day there's 24 hours in the day we have them split them four hours apart we've put them more or less two and a half hours apart but then it leaves us six seven hour gap where I can do maintenance yeah so actually literally taken what could potentially be two more trains lots and may get them moving maintenance Lots so in the morning I maintain in the southern part of the line hmm train is that a moving on the north and about one o'clock they get halfway I stop all the maintenance on the southern part of the line and ask about maintenance in the northern part I've actually got a maintenance window in the 24-hour period and most of that we do maintenance every day without disrupting transits and there is something it is so many different feeding points into the network that it becomes a bit complex to do it that way so we have been forced to take maintenance loss by disrupting planned operations obviously that scenario with is so many different variables and complexity difficult to have predictive maintenance that means that yeah this can I share one slide with you quickly and then we go back to your document I give this slide when I was we're working with the strategy team and this is just I called it at the time capacity 101 for dummies the UIC Sydney booklet or leaflet actually says in railways capacity per se doesn't exist in railways is purely a function of utilization of installed engineering design they identify a few things that influence how well you can use infrastructure one of them being the design itself hmm axial loading whether you have single or double ions which we've spoken about the design of your gradients your curves because obviously if the gradients the steeper you move slower means the gradients if the gradients are easier you can move for now say your level of engineering it's basically these elements are strong all right then it's the technology in the rolling stock you have and then it comes to the things you're talking about which is high designed your schedule and how you've designed your operating philosophy on the one critical which is very seldom spoken about in each papists he's organizing nation culture yes so there's a much higher culture of precision in the revelers in Australia for itself then here hmm we often say morals nor Fattah in Australia you don't have that so these are the things that determine your capacity

RK

yes

TE

what I didn't do on the right-hand side is I took a few basic examples in this example I said if you go to one of the old technologies we have which is vacuum break wagons they limit you to 40 wagon train and some of the old infrastructures was designed it 16 tones Paxil so in that scenario if you had nine-point six slots available it would give you an output of just under 17,000 tons per week if all you did is replace the vacuum break with a brake and replace the friction bearing with roller bearing you could suddenly run long trains so just by changing the wagon technology the number of slots hasn't changed which means you've not changed your installed infrastructure but you've more than doubled your throughput

RK

yes

TE

if you then further invest in axial node so you start to move from 20 tons per axle to 26 transparent so and this can be done but limited engineering making the Belles impaired bigger slowing down the speed of the trains so that you've put more control and reduce the forces on the network the same number of circuits suddenly give you sixty thousand tons per week throughput capability so I've increased capacity and throughput without changing install the infrastructure if you then take the single line example and you extend some of the loops which means you can fit longer trains on to the line I still haven't changed the number of slots I have but if you look at this I've moved from just under seventeen thousand to almost eighty one thousand tons per week I've not significantly put in infrastructure now I'd start exploiting technologies some of our networks 3kv some of them 25 kV and the old line is 50 kV in terms of the electrical networks so by installing new voltage capability on the locomotives I eliminate the change over time because that is a bottleneck in this example it was on the code line by eliminating the change over time I took out we each a locomotives you first have to pull up your air break your air in the train because it's the air that stops the train that process alone and the coal light was two and a half hours so by removing that without putting more infrastructure in the ground I unlocked a further almost four slots and this is what I was saying if I if you eliminate standing time you create capacity so far have not done in tree infrastructure so I have exploited wagon technologies I've done a little bit of loop extensions which is an infrastructure intervention and I've used technology on locomotives and suddenly kidding 116 thousand tons introduced distributed power which means instead of having all the locomotives in front of the trains I have locomotives between the train what that does is it shortens the acceleration curve in the braking curve because naturally short rains I'm so close to each other that they combined

RK

yeah

TE

so I can then have better velocity because I'm using less distance to slow down and less distance to takeoff which allows me to move trains closer to each other and in this example I've gone from seventy thousand tons and thirty-two thousand times per week with up building new infrastructure.

RK

That's good work what did people say when they saw this because I mean well maybe understand y'all will be good if you do it but when you have these numbers yeah it did people's attention right this is money we're talking about if you manage to do that right its income revenue

TE

we did this and we tested it with the engineers and I've given it to profit sterling Bosch and we've given it to the USD and they came back and based on the feedback that they got we much to the engineer's dismay stopped a number of the capital expansion programs and assembled them you don't need the money hmm go in get creative so we've avoided some unnecessary capital expenditure the project that I was responsible for when we did this exercise the initial indication was it was going to be a twenty billion over a seven-year project we reduced it to a three off billion over seven-year project do

RK

wow they give you a raise and a promotion that a point

TE

but I'll fill the slide to you I don't know if you can still use this but it talks to what you started with which was saying before I spend capital let me make sure it's Austin all the alternatives

RK

yeah I mean for sure it will be useful and the framework that I've made up till now even up to the point where I'm goanna show you we have come to even that is not even yet let's say 70% of the research yes it is in terms of effort but not in terms of value add the discussion in the conclusion are so very important sections so if I come and I say okay this issue this is great to think only in terms of operational measures but also trade-off analysis early by looking at technology even though it's is spending some money it's so spending a lot less than building track I think we all know how much it costs per kilometer to build and that's insane sometimes just changing the brakes and those things can be you know ten times more beneficial in the long run so that's perfectly valid content for discussion well thank you that's great okay cool let me we're getting they were getting they were making burgers okay let me go back to document yeah so you are pretty much like what you were saying I can bit quicker through these parts the contributors to capacity in general your link stock the signaling in operations timetabling and service design stations and infrastructure you know those are the main things that determine what your capacity is it definitely not any of those in isolation okay now I just basically say that I went and did some digging with a lot of resources and I checked the references and make sure to use only strong ones but the next section that come it was based off of those and now I basically just giving some examples for each of the different kinds of capacity so in terms of theoretical theoretical will dictate you know the network effects heterogeneity these are all things that you were saying those first few points on that slide these are those are the things that I'm taking as con change for the sake of my research those are all things that are going to get input and I'm working on this level which is saying okay what are the maintenance strategies the operational strategies and what we determined to be acceptable levels of reliability and then practical capacity that's again one level down which will be condition based availability and abnormalities condition and then used again which is demand I'm just looking at this level okay now I get into the juicy stuff okay well let's see I'll just want this to go in okay which is the big chunk of it which is maintenance and operational allowances and this is where I think about how can me define them more clearly and then evaluate them so in terms of operational allowances this is where I had a focus group I actually just sat in on a focus group that was held at the TCS see where people who are trying to understand what leads to stage cancel then delayed trains let me see if I can quickly just zoom sorry for the craziness more to come what was just showing there but these are the kind of things that we produced were these mind maps if you will by people saying you know a whole team of people sitting down together and saying okay what are the contributors to council trains and then going in and listing all sorts of things that we did for delayed and staged - with you if you want this information

TE

I can share that with you in return for it so useful for your great I'm

RK

so yeah circular one I saw just now as you scroll down yes it was about the synthesis evaluation and sorry

TE

I noticed that one of the authors you've quoted is Schmidt have you looked extensively at his work

RK

um well they must have been a paper or two that was that I did everything I've courted you I read in its entirety which pits

TE

are you referring to specifically one with blue arrows

RK

oh yeah was it this one

TE

this one is a big flick arrows as us calling darkness

RK

oh yeah I think okay we'll come to that no hmm yeah I think I know Johnny Drama okay so okay yeah so basically yeah I'll just I'll get you there so I'm just looking for my charger as I'm speaking so you are and basically just summarize saying these are the main operational factors or let's say factors that you have to consider on the operational allowance I'd like some of them are related to maintenance and I've been cleaning that in the next section for example rail network maintenance but these were just this is just a summary by saying that okay maybe for any certain segment of the network whether it's online or network and you can look at this and say these are the factors so you base this on the history and good data to produce some sort of chart to say okay and generally we know that these are the contributors that meat suit stage canceled and delayed trains therefore these are the things that we should be budgeting into our allowance and for various segments this distribution will differ right so that's basically what I'm saying we have no control over the environmental and social directly and some of that maybe can be you can preempt just a small portion of an allowance to battle for that but in general you'll mainly be talking about you know and the operation side of things some of these are more condition dependent but it depends on what your strategy and philosophy is towards buffering against risk I suppose what your risk appetite is does I think say and then I speaks to you then I makes I mean I speak about the nature of the cargo that is also an important consideration for the amount of allowance that you afford what kind of tolerance the customers have on how late it can be that will also determine maybe if they're very comfortable with delay for example depending on what the things would be for example coal over something agricultural where the food critics file or something like that and you might say okay cool will run with tighter margins and take a chance right but the consequence of being late from the customers perspective depending on summers will affect how bad it is and then yeah so then I just spoke about some operational challenges and this again it might be relate to the cultural aspects as well but these are things that are very difficult to overcome you know lack of strategy with the challenges between organizations conflicts when these different operators on the same line here it could be multiple operators but then also speaking about passenger and freight that's an important thing and then misalignment between operation and Des Moines so this is just again saying that there is obviously this afraid system exists within a bigger system and we can cater for some of these challenges to a certain extent but we also are trying to balance that with the business needs to make as much money as possible but also to do that within a certain level of acceptable performance and happy employees and those sort of things because knocking on problems just leads to bigger problems you know so um that's what I've got over there then diving into the maintenance allowances so the first thing was identifying the kind of maintenance that transit usually has to do on the infrastructure and these are the different things I don't necessarily know what each of them are but that's okay for the sake of this research these are the different kind of activities that people could do and then I died I drove into yes so now it's speaking specifically about me

TE

that's an interesting word just on a side note what is the right word is it I die do I do interest I don't I do it's weird but like I Drive I drove by my dog people always look at me funny with those words

RK

you know what I saw them like I'm doing engineering you know I'm not a writer or anything like that I enjoy writing but please look to Merriam-webster for those answers or laugh at me I'm fine with you liking it but don't expect me to know okay so then, therefore, there are the main considerations are okay looking at the interdependencies between infrastructure and trains, for example, the materials right that will dictate often you might have to do maintenance on the assets and the infrastructure it's metal-on-metal in most cases depending on which materials you use what it takes how much maintenance you have to do the layout of the network the more stretched out certain things are from each other the more planning you'd have to do and if you have a situation where you contract maintenance out the longer lead time you'd have to do so it's the geographical layout as well as the layout of contributing elements that make the maintenance happen or all considerations these are just important considerations for how much maintenance you have to do in safety I beg your pardon

TE

I must tell Lloyd to improve for you understand that I'll repeat to them many

RK

well you'd be surprised what a few years of reading papers can be for you but um you know I I actually who knows about the future is Lloyd your senior or do you
guys work side by side

TE

Lloyd guys work side by side chief executives I report to you

RK

oh okay I felt like kind of bold I just messaged him on LinkedIn and I was like I need somebody to help me and then he suggested you it was like I use your back and it was very immediate as well thank you that's what I wanted was somebody speak to you know I'm Lloyd he was someone I was just old on LinkedIn because a lot of people won't reply to emails and things like that le I've had the one focus group I mean people are very busy I understand but like I was like I need to be done and maybe this will be helpful to people you know that's a two-way street hopefully and then the safety aspect obviously certain regions or more stringent safety things certain yeah so safety is important let's see here I'm my strength of the signals not so good tummies can you still hear me okay cool and then and your organization and deregulation or is this I don't think it's supposed to be Dee I think if that's really regulation so on how the actual system is organized that will also have an influence on maintenance again it has to do with the distribution actually sorry to go back the fourth point is what I was saying about the distribution of the network and the physical components as well as the organization of contractors the second point was to do about what the impact is of one maintenance activity on the rest of the network so certain components on both your maintaining like the signaling system or something that is going to affect a larger portion of the network where some things are very local so understanding the significance of that as well will affect your planning for it and then now some other considerations or what the actual maintenance is that you have to do the preconditions for those tasks the equipment and the crews that you need how long you need to actually possess a certain segment of the network the degree of coordination the costs and how the maintenance will vary with seasons you know depending on how extreme the way there is in a certain climate that will have a sigma significant effect and then like you said this is what you're speaking about earlier is it a proactive or reactive maintenance strategy diagnostic versus restarted which again is technology related right how much you can diagnose before time and then the capacity is in planning horizon so these are more strategic aspects that are decided upon but that will feed directly into your maintenance allowance decisions if you're going to have more of a diagnostic approach you would need sure maybe allow for less maintenance in your timetable because you know that you can just diagnose it and then predict and then just do a very narrow the maintenance on exactly the portion that's needed when it's needed but if you need to restore you need to probably allow more time right because that's kind of like a lagging instead of leading approach yeah so capacity planning is this what you're speaking about the thing with the arrows or no

TE

yeah that I was interested in seeing

RK

yeah so this is we're basically just summarize when you plan for capacity what the process is you assist what you have your sis what you need you develop options for how to meet that need you evaluate between them again it's that idea of like making a decision and then you select the best option all right very simple but highlighting that yes exactly that's one that's a very very very good alternative for matching the demand right and then I started speaking about scheduled railways so translators it's in 2011 that they started to introduce scheduled railways whereas before they've been doing it on a 10 inch base system basically waiting until the Train is full and then moving it so that was actually a critical turning point because I'm sure that the performance in general winds up evidence shows that applying even though it's a passenger in like first initiated approach it works very well for Freight to so then the concept of schedule came up and then here I just highlighted the difference I think this actually all this came from my goobers presentation the difference between passenger and freight considerations for scheduled railway you know it's a different story so even though we can apply the lessons this is different considerations yeah I mean yeah then I started to speak a little bit about the operational side of things and and how this feeds into the scheduling so I'll show you a diagram that I have below here which okay it's very No see if I can okay so now this is basically where I try to incorporate it this is basically me summarizing the operations of the railway network you know very high-level so this again has about how you know relationship between the cars are they get how you both blocks how they then move the decisions are made in service network design what contributes towards service network design the customers applying demand on the network and then this is the complexity is related to the space economic sometime you have to meet those constraints basically but somehow all of this together so this is I guess at one level a summary of a lot of content that I read basically showing the relationship and again reinforcing the complexity because all of this has to be done simultaneously

TE

who you understand it there's nothing that I can offer you

RK

No no no okay we're getting to the juicy bits okay so then tiny tabling okay so now that we spoke about queso scheduling is good then the significance of time tables in the schedule so basically over here I like the quote that I that came from this oyster he said time tables declare okay also he took place at the time table in that evaluation should produce objective quantitative information about the expected operational performance of the rail line later from the viewpoint of the stakeholders in order to support management and decision-making and performance improvement so time tables are kind of like that in that interface if you want to between you know the operators and you know the infrastructure owners and everything like that and actually what's happening on the network it's the translation between taking everything we know about what we can do and presenting it and operating it and managing it in a way where we actually execute what we think that we can do it's the formalization of bringing everything together is the timetable as part of the service design so we I dive into the timetable evaluation matrix so now I'm looking at this as the perspective of okay cool so every single stakeholder will perhaps have a different metric again when linking it back to the previous part different stakeholders different perspective they four different things that they'd be interested in and yeah this is basically all bringing it together use all these things in bold italics are the same stakeholders from the diagram from four add that addicted so these interest areas or the specific metrics that could be used for timetable evaluation these are the stakeholders from the perspective and a specific metric specific matrix for each of these interest areas and the whole thing again is the time table presents a view of the operational performance the predicted operational performance of the railway nickel from the perspective of the stakeholder because you're basically presenting it to them you need to be able to solve the slots and everything like that you need to translate everything like I showed in that complex diagram and put it together in a time table right that's one of the most significant things that you can produce our stakeholder

TE

I like the service design perspective of the stakeholder

RK

yes that's very vey strong and also very related to systems engineering and now we've got 30 minutes left and now I'm getting him just a cheesy pizza okay so assistance engineering approaches to evaluation so I speak about two specific things which are exactly what's contained in my conceptual framework so um let me know if you're familiar with these terms are we evaluating if not I'm definitely goanna go into it in any case so I'll just bring up the example of the value model because this forms one component of my constituent which is basically hybridizing these two very popular methods to eliminate the weaknesses and to maximize on the strengths so normally this very morning this is part of what my company teaches as we go to companies and teach them you know part of the things we do is to teach them how to do this for their designs so here we have an example of one for a railway crossing but basically you sit down so now the worst column represents and this potentially could be your 65% factors the worst column represents the absolute bare minimum that the customer is willing to accept these are the requirements the whole value model is geared towards improving on the absolutely bare minimum so we're not talking about not meeting the requirements they may be business meaning there may be demand needs I know that transit is always concert with like I'm obtaining a proportion of the market all of that would feed into a requirement if you don't meet the requirements like somebody's going to get fired so to speak you know okay that's a bad way of putting it but I watch a lot of sports so that's my excuse for saying that so yeah the worst is the requirement the best is within feasible within what's feasible right because obviously we'd want the base cost to be zero you know we'd want availability to be okay here actually they did say one was based but that's very unrealistic you can almost never get a hundred percent availability but basically within what's feasible with technology with other constraints time budget all of those what's the absolute pace that can be achieved in the priority this part is sort of standard rights is going through each of them and basically the question that we ask is we'll say given that you can only make one of these mo switch on measures of effectiveness well right which are all things so they're the actual requirements document itself they could have been thousands of requirements this is saying we're picking seven to fifteen of them is the usual number we suggest seven to fifteen measures that if you can't improve on them we should focus on improving on them because they will increase your perception of value that's the basic thing so priority is saying okay cool so given that you can only improve one of these things which is going to be the most important one and in this case they said failsafe reliability because if something goes wrong and the train crashes that is way worse than any value gained from you know the third investment cost and then you work like that so first they failsafe reliability then safety which is obviously always important in the railroad you know somebody dying is always a very bad thing and always worse you know to have safety to have risk of safety rather than gains of investment of income let's say because the value life is valued I'm more than this is this is how it should be right then reduction of speed I mean sorry reduction of tracks needed was three and you go on and on and on this is kind of standard but the way the value is of the value model is in this part Queens so with this way of prioritizing all of the measures are equally spaced but if we say we assign one hundred to the number one priority now we can create bigger separation between each of these Emory's because often it's not just distributed like you can see that in this case number eight nine and ten all have little points of one which means they don't really care about improvements that could be made in these three areas what they care about the most number one two and three with one two and three having a linear change of a value perception so this allows for greater separation it's basically like an improvement on this priority column in giving awaits to each of them and now the UFC's is interesting again because now we're saying value does not change equally over this worse to base range so I'll take an example like this one over here which is saying that if my costs changes from 150,000 being the being the best per investment cost to 250,000 and so it gets to about a hundred and eighty thousand it's so like ten out of ten for me an improvement to one hundred and eighty thousand is very great but once we start dropping once it starts costing more than one hundred and eighty thousand my it's becoming problematic for me my perception of value is changing from that worst to best range which is again the value of this that's not always captured so some are linear but for some this stepwise function change and for some it's like this exponential thing and sitting down with the stakeholder is something we like you know really encourage our clients to do is to get you know at least representation from the stakeholders of how value changes over this range because it can really direct you in terms of selecting the best design if you can improve in your cost just a little bit that is a very good improvement of value for the stakeholders for example okay so that's what we call the system effectiveness model which exists whether there are alternatives or not then the effectiveness evaluation is saying like let's take now a particular design which in this case was a particular example of a railway crossing design and we make informed predictions based on experience available data simulation and all sorts of things about how we expect it to perform all right so this is not factual about but we have enough evidence to say that we expect it to be so like for example here the value of the mo e okay I'll use they face from cost since we were talking about that we say a hundred seventy is what we predicted to cost from for the operational and service cross we expect that to be 220,000 and you can't go and make predictions for all of these then you multiply that value by I mean sorry then you go on to this cross over here I'll use the cost one again and you say okay I expect that it will cost 170,000 I go to the utility function and that's a 10 out of 10 so I put a tin on the RVC then I'm multiplying relative value contribution so taking into consideration the utility function and then ABC is C what is it I think overall no sorry it's actual value contribution sorry I think people are trying to look for me I just give me one second with my oh really I'll be like another 25 minutes but I don't want to taking the bus okay thank you see you tomorrow I hope you weren't waiting for me Thank You Darren okay thank you so much thank you for your patience okay so where was I okay yeah so basically this column is I'll show you what it means I'm just now multiplying the relative contribution by the weight to get an impression of basically the weighted value now so it's a really involved waiting thanks Darren he's a very very talented but slightly crazy I'm TV I work with okay so this you understand do you understand the value model

TE

yes I think it makes sense to me

RK

all of these red bands show uncertainty so those are a probability density functions because we can't even know for sure right so we would do they would have a probability distribution function in proportion to how much risk is involved with that estimate then we add the total of this ABC and we come up with some number the number on its own is meaningless because one of the values of the value model is that you're taking measures with different units completely different units but you're bringing it into one table getting rid of the unit's through the introduction of the waiting and the in the utility function but then what happens is if you're comparing multiple designs this number becomes very valuable so they said like okay the same thing was done over a different design and the answer was four or two and then you also consider what amount of uncertainty you have so your risk involved with either of these numbers and then you pick a decision based off of that so it's a short story to a very long story I hope I didn't do too much of a bad job of explaining how it works but it's a very useful thing for making decisions when you have the input of the stakeholders to figure out what the best solution is for any problem

TE

it's certainly very useful to me

RK

yeah I know it's really good this has been one of the things that have really changed the trajectory of why engineering is being able to identify the things that contributed most to stakeholders value and we use this even internally from DIF I'm looking at each of the clients that we do on-site work with we have communication with them, in the beginning, to determine which aspects will be the most important to them which outcomes are the things that they're looking for the most so instead of spending so much time and money creating beautiful powerful PowerPoint presentations we've realized that if we try to put in a lot of effort to find out what to them is success and we prioritize them we can dedicate our time accordingly because as you know everything takes twice as long as you expect it to so we almost always run out of time but we can focus on the things that most of them okay y'all so that's just a repetition of the above and then and then the second thing is the QFT are you familiar with the quality function deployment

TE

no

RK

okay so I'll just go into this example and I'll make this part quick because I have to jump into fun part now so basically the QFT is you take the customer specifications which in my conceptual model are those timetable evaluation matrix because this is what comes from the customer as things that are very important to them the house of quality is usually used when you have a product that you sell and you have competitors who saw the same product and you very have a very clear understanding of the technology that you're going to use in developing that product and you have some idea of the relationship between each of those technological elements and the relationship to those customer needs

TE

so it makes sense to me it's similar to some model that we used for advanced for teaching management at IMD they call it something different the concept makes sense to me

RK

okay great you know there are so many variations of this house of quality function deployment those are the common terms but there are so many variations so meaning this is a very simplified view actually and then here is where you go and say okay our product what do we which product as they did in a slightly different way but you go and you rank so they put okay the one custom the one competitor they rank most strongly in this quiet department this is for a drone battery life this competitor has the strongest performance and then going on like that then the roof of the house allows you to establish the relationship between the technology so if you think of this as this row as the controlled factors and this row as the stakeholder needs I mean that's simply and the relationship between them here that's what you do then what this basically does is part over here is it convolved these items so you're basically summing who each of the technologies what impact do they have on the customer specification so you can see that looking at this one so the minutes so I guess that relates to battery life so the more powerful or let's say the amount of flying time that the drone has is strongly related to a lot of aspects of the customer needs and therefore if there is anything that is going to improve upon it to this one but they may have competitive designs to see both of our customers performance of waste in these areas and how can we learn from them to adjust our design it's just one application of how it can be used yeah okay and now I'm sorry what's that all right okay sorry it's very sticky I'm the connection so some point opening here and sometimes not so much okay now at least this part should be a little bit easier now that I've explained all of this to you yeah so what I've basically done is I've realized that there there's a strength and a weakness between some of the value model the strengths is that you get good separation between the stakeholder needs and the introduction of the utility function which is really good right so it shows how the value particular angles from the worst of the best it also it's there be a worst by saying that this is what is acceptable to me well then the tough part is that it looks at the system as a war as a white as a black box so you're basically saying like okay from the customers perspective I don't necessarily know care about what the inner workings are but when I look at the system as a whole these are the things that are important to me I've identified him in this in this column over here so these are the things that come from the time table evaluation methods I thought this only on the operational and maintenance related operation and maintenance related aspects to come up with the lists of things that would be the most important put each of those six stakeholders identified in that initial diagram these are the ones that I've pointed out and I'll just go over it quickly and then I'll zoom in to parcel you can please give me your feedback on them then what I said is okay for the so when coming up with operational capacity there are maintenance and operational factors that each contribute risk so thinking of it as thinking of allowance as a step to mitigate risk allowed me to phrase each of these bands so I phrase them all with the perspective of that mole is negative or let's say not negative more of each of these things will decrease operational capacity what I phrased it because simply requires a certain level of allowance to contract the risk from having more of these so each of these increases the risks towards basically maximizing operational capacity and then and this is the part where I just this is all very much just randomly populated to show the utility of it because the relationships the conceptual part of the framework is basically assembling this the content of this is true or let me not say true or research risk content is accurate using the utility functions are accurate to my research and I'll show you a little bit about how I came up with a simple utility function and then again this is all fictitious population against me for example this is a one specific time table because it is actually a different another diagram that I should have shown you and I'm trying to rush a bit with the time but I will show you because it says that has significance each of these time tables with experience and input data will have a certain expected amount of delays that would be secondary delay per 100 kilometers density on their brute energy efficiency co2 emissions and all of these relate to the various stakeholders values or

TE

those are tolerances these are top ones

RK

no that's not that's not tolerances let's see if we can find the unit over here wait it's minutes per 100 I pray in Kalama because it's not about tolerance it's about anticipated amount of delay so these are all the customer basically saying what the customer the stakeholders getting together anything I have a certain expectation what the revenue will be between this range and this range I've been the efficient that the volume on sorted or fishy format for operator specific will be between the change and the change in a requirement and so on does it make sense what's contained in this column and then over here or basically all the possible impedances to being able to meet musical agent and that's why this operational and maintenance allows in the first place is because these are there are risks to not being able to meet it but we learned this allow for it to go not go according to can we put any fun profits so then at the end of each of those columns you then have a weight contribution to each of their controlled factors is the terminology for this one each of the control factors that contribute to the let's say that having the strongest influence on being able to meet the stakeholder needs and then there is a waiting for them there then what you do is you rate so over here we rated each of the timetables according to the anticipated expectation to I mean the expected so remember all these timetables would be chosen because they meet the minimum requirements that's the thing is that this is all saying they will be have at least the minimum expected performance but mile from where for the best of the options we found what we choose so then we score them on each of these factors and then we come up with that rating here this is total things are relative value at the bottom so remember the number them salt which itself is not so important but really the numbers are important so this white this timetable to seemingly had beliefs value as well it would have the least ability to exceed expectation of the customer in terms of the worst requirements and it would it say come short of with base requirements whereas the best one was this one the base timetable was this one over here okay Lin in this column the section of the of the framework what I did was I said okay so it's kind of difficult to very accurately predict the amount of risk associated with each of these you can go off of experience you can make some judgments but in this case we seem to know a lot about density about emissions revenue on specific that with that we have lots of data on where as with these factors they are a little bit more subject to vary due to many many aspects and usually there'll be a lot of work that's done to improve them so I can't predict when with this granularity so in these cases I just scored each of the timetables on the risk factor with five new greatest risk in that area and and one being the least risk so basically by just saying if I think there's a hell of a lot of risk there I'll give it a five if I think that there's minor risk associated with that I'll give it a one then I found the unit risk for each of the areas which then allowed me to see which timetable has the most it has the most risk associated with it we risk is risk is defined as the potential to not meet the outcome that's desired so this point a time table number five presented the biggest three not meeting the customer or sorry the stakeholder expectation time table one presented the best ability to meet for the best value so you I thought I like to think of it is this area is my opportunity because it's all about the value model the contributing value and this is all about the risk because it's all about operation and maintenance factors and the compromise that they would have on those same custom needs so the thing is that this whole section is combining each of these elements with the customer needs to come up with an overall risk over here so then I took a risk and I subtracted the value so now it's all in because projects in general they fail more than they succeed in general and there is more risk than opportunity and the way that I did this calculation and all of the risk factors were where the risk is always higher than opportunity with any engineering project that you do in any case there's that's just the nature of how it works so I subtracted the opportunity from risk and then I came up with the evaluation because I reduced both segments to the unit opportunity unit first I could subtract the one from the other and then it turns out that the best timetable to operate with a boom time table number four because even though it only has the second highest value it has a pretty reasonably low risk in comparison with some of the others so this is the best

TE

time to universes probably then also true that you've got the highest probability of success in terms of delivering a timetable

RK

exactly because both of these okay this segment is just the value model which I showed you before but this is considering so this gives you the white-box approach that's what's nice about the house of quality you get the white box approaches looking at the system by clicking it for example position required and preconditions and effects the greater position required the more challenging it's going to be for me to my client's operation the most stringent the preconditions and the amount and the faster they effects from the maintenance the more challenging it's going to be operational requirements I mean operational capacity and that's why in some these are phrased in that same way where all of them are phrased as risk factors and then this is that you're the convolved section and then yacht so this is that's my framework is putting together those two aspects the value model and the house of quality I just want to show you one more thing which I think will bring it together with a little

TE

This is brilliant

RK

you know what I will maybe ask from you is because our time is running a little bit short and is what I'll do is I'll send you because I can't send you there Oh actually no I do trust you I press you I'll send you the framework because it exists that way would you mind looking closely at the actual specific the specific things in the column member and the columns and the rows and giving me critique on them because yeah obviously there's a whole chunk of work that we've gotten through today but what I would like your take on is what I researched which is not the framework itself is nice to look at but the content of what's in there comes from reading many papers and conducts and everything like that so if that's okay with you I would like for your input thank you so much and we know what's your availability like over the next few days weeks months when do you think that you'd be able to give me speak on that for my planning

TE

can get Monitor to set that up but probably I'm traveling out the country next week from Tuesday to Friday so probably on the 9th

RK

on the 9th okay

TE

which is not Monday coming it's Monday a week later traveling the country next week from Tuesday to Friday I would offer you Monday but my assignment is the 9th will work perfectly

RK

okay that's awesome that's great I'm sorry I'm young would you mind asking money to set up and then what I'll do is I'll send you the information in the meantime that may be on your flight so when you have absolutely nothing better to do you can read through and then we can just discuss critique of your framework plan the specifics of it and get into their the nitty-gritty

TE

we can take the same time slot because I think it's probably the law was convenient

RK

yeah I'm at that point I'll be back in South Africa though so I it's works I'll be back at this weekend so yeah this over here is basically me putting together this is a very condensed summary of all the research I did in chapter 2 so basically you know you have your theoretical your operational and your use capacity that correspond with the planning construction and wind operation we think if we look like the railway infrastructure I'm a crime table perspective we have to do all of these things my research and I still have to indicated is concerned with this area over here so it actually falls into the tactical aspect when you talk about planning more the tactical preparation for operational so what I'm hoping is that this framework can be used to develop as part of identifying ways to modify capacity as would you as with your example that you gave of like you know looking at the different ways to treat to use technology it would also fall into this considering the different ways to meet capacity and then basically timetable variations coming up with let's say conceptual high level timetable options where you just think about what the high level timetable before you get really into the detail and you know growing we think your service design that would be concluded at the end of this and then you construct the timetable in higher detail as a result of this work so the second part over here is basically where I think this research will fit and this just basically highlights the factors that go into influences so you have your requirements coming from the stakeholders right in the beginning you consider your strategy or you're sorry the requirements come in as part of the strategy this framework takes the strategic inputs as well as some other known information about the network creates a high-level timetable of versions of them and select the fifth one taking into consideration the risk on opportunity and then further evolves the base timetable in time and effort and energy on that and as well the simulation of timetables is so it's a very expensive long press it's good but I'm just trying to find a more user-friendly easier to apply but so valuable way to actually you evaluate timetables considering operational capacity and the fact that with maintenance and operational risk associated with the climb table it's not the suppressant dry point because again it's about the service envelopes which is why we're not just looking at you know what the stakeholders needs it's about looking at the whole thing coming together and there's many considerations and then

TE

it's the magic way of ensuring that the final decision you make is one that will be viable gospel

RK

exactly so it's like it's somewhere between just taking a thumbs up as to what you think would be the best approach and doing like a detailed simulation it's somewhere between there it's sort of like the middle ground which basically informs or let me say motivates further effort in traverse design because I'm not sure about how it works for different railway companies but sometimes too many efforts are taken too far on too many different timetable versions and you know the resources just aren't there to allow for that all the time and energy could be other places or sometimes the potential candidate disrupt properly because right factors were not considered this is some way in the middle here is the weirdest research you are so that's it and this was such a long meeting and thank you for being so patient with me

TE

I like it I was saying to you just now absolute sense to me array I wish more of the people I work with think on this level but I can understand having looked at your profile why this comes naturally to you I was saying I see one of the authors that you referred to is if you've got access to your emails I just extracted from the document that I looked at let me just share it with you quickly let me see I should have stopped sharing which would allow you there we go

RK

zoom is very interesting it can be quite Moody I don't know are you is it obvious

TE

I mean if I'm looking at the right things from Lake City and he simply finds it the area that you've spoken about quite extensively is down here but also you've got various components of these so I think there isn't they shouldn't be in terms of anybody reviewing your work perception that there's something left out I think it's quite complete just based on my understanding of this model this one basically says if you look at the overview of railways is a subsystem you plan services you plan operations maintenance then you need to manage the movement across the network which is command and control this the actual methodology of operating so you either pulling the load or telling it to you trying to retarder to stop it and then there's a whole of external support that you need it then goes to which are the key components of the railways that contribute to each of these and on the other hand what are the other inputs that you require so a lot of what you've spoken about sorry is around that area you touched on ten surfaces which is why this some reference to demand on the one side and some basic rules of the other side but the bulk of it is around how to arrive at an optimal schedule so I can be able to deliver the demand I'm looking for and you have pretty much looked at what does this mean resources although you haven't gone into any significant detail but in it fits perfectly into what I've been reading for my own studies and I found this authors models rather complex the tea and railway integration to be very practical there's not complex terms and words it's something that's easy for it

RK

yeah you need also there's means so many technical things new just like you just simplify a piece this is great images powerful

TE

then you had a list of elements of maintenance that suggesting you read through it I came across this also from the same author which just gives a very simple summary of what is in the infrastructure and although I haven't put the whole paper here because it was a very long paper, in summary, he is saying in that direction here you need to ensure absolute certainty in engineering because the lower levels you want to maintain less he goes to the point of saying if you ever need to do maintenance at this level it means the entire infrastructure status so you want to get to your maintenance to the top areas because this is where your moving parts are and this is where you interface with the Train so railway maintenance should largely be limited to those three elements and these should be engineered to last for a very long time and if you ever need to get into space either you've not managed maintenance on those three correctly so you've allowed water to come into this, hmm oh you've just not engineered correctly from the beginning but when he unused them from this layer from the surface layer down the last time you should need to touch that is when you build it

RK

oh wow that says a lot doesn't it if you do that you should you know the big I love that

TE

so I also found the name of the website which is published and you know Wow I mean it's like you say relying on one or

RK

That is not good but sometimes all you need is a certain thing to be expressed in a certain way that can just be like the turning point for you in your research and I mean like a lot of people are very academic out there confusing things you know speaking in a convoluted way it's so difficult to understand that when you get something like this a good picture can have contained thousands beyond so this is excellent this is great thank you this one I thought I every railway's light

TE

you were talking about the different stakeholder requirements I think this aspect here kind of starts to touch on some of those in a simple but not simplistic way yes right and that's the thing simple but not simplistic

RK

that's all we could ever one from our research from our word

TE

I must say after I came across these models I went back to some of the papers they confused that's amazing it's a type of thinking to it but I've emailed this to you

RK

thank you I saw that thank you so much that'll be very helpful I'm gonna dive in thank you

TE

just one more thing I wanted to show you at least to the test and I know you're out of time

RK

I'm good with time I just don't want to keep you racing forever but I'm good with time this is a beautiful opportunity that I have yes oh I would not want you - what time do you have to go buy more units amid me or her -

TE

commitments at 10 o'clock but I've just signaled the guys they're out you have to signal them to have coffee in the meantime picking up the next document alone -

RK

is it saying like as a read error is it a PDF is it not one of the tabs or is it something else a window

TE

it is a PDF document I'm not sure why it doesn't want me to share it okay I'll figure out what's wrong with it I'll extract it in an email it to you but it's basically it's probably that I had done on railway systems integration which I did it for facilitating a discussion that I had with one of the team's I was working with a few years ago just trying to create a simple view of understanding how this business works but I'll figure out how to simplify it and then I'll share it with you it's part of a bigger document and I only have the PDF versions how to set forgot how to extract the parts of it that I can say you know right well so it basically talks to the different components of what makes the railway system complex and it's stuck again it's not allowing me to page okay this is not goanna work my goodness technology as it's been one of those days on this end anyway so I was I was talking to you about volume over distance and what we did here and this is the Harris model that that we applied used in some numbers that we drew this particular style I won't share with you I've deliberately taken off the date so that you don't see when the information is relevant to this TV if you apply the Harris model the longer the distance the lower your operating cost although in terms of your total cost obviously over longer distances you engineer not more because you pull my travel to see a capital casa separate slide what I then showed was the inverse relationship between your transport cost of distance and your capital cost all over the same distance but what you did find is because you spend your capital upfront and if you go back to the slide I showed you of the railway components if you break your capital what went into which component the last three components you can actually on the rise over 5,200 years and what if then does is your variable cost increases with inflation but your capital cost is protected against inflation so what you find is if you have a higher capital cost initially in the lower operating costs so if for argument's sake the answer is 10 in your capital cost is 7 and your operating cost is 3 over time the 3 will increase to maybe a 5 for argument's sake the 7 as you pay it off will come down to a point where it's zero at that point where you would have started with 10 your total well then be 8 which means you've got some room to upgrade or refurbish without pricing yourself out of the market whereas if you started with a higher operating cost of mints a seven-member cost of B the three would become zero the seven would go up with inflation by the hidden by the time the three become zero your total cost could have exceeded ten and you start pricing yourself at market books - why a lot of the road companies replace their vehicles as often as they do so that you have a much higher capital cost and operating cost it also - why so many of the railways around the world in the last few years have aggressively started to spend capital but a lot of them have started to spend capital as a way of managing their sustainability and restructuring the income statements and balance sheets rather than create capacity University is primarily created through exploiting the existing infrastructure which I think your paper kind of brings us there because it shows if you are going to spend capital it must be to reduce your risk because in terms of the stakeholder requirements your model has already showed you if are the two options it bring you closer to meet you take all the requirements of the variable is the ability to optimize or mitigate your risk so that's the study now to complicate your rescue either eliminated which means you know you financed it through insurance oh you injured your it out financing it through insurance is the expensive because operating also gives you the last two options which are much cheaper capital cost than building new infrastructure

RK

Wow you know this is so great because this because my study like I was saying it's really in that as the short part of the tactical decision and planning horizon but your work cut brings a full circle so it's like all of these are feeding into each other you know when you evaluate the time table and you say okay well this one it really has such a much lower I'm operating costs but it's not performing as well in these areas and you realize they could be a technology-based point solution that allows you to perform much better and even reduce operating costs further it's like you can synergize these you know these methods and find a long-term approach for better meeting the demand

TE

okay