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Applying Systems Engineering to Optimise the Operation and Maintenance of Railway Vehicles throughout the Value Chain

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Abstract
A recent move by the UK government to purchase two new railway vehicle fleets from the provider offering the lowest whole-life, whole-system cost creates significant challenges to traditional manufacturers and their extended enterprises.

This paper describes the work of a collaborative academic-industry research project; applying systems engineering to enable the optimisation of the operation and maintenance of railway vehicles – one aspect of railway vehicles' lives which will need to be fully understood in order to offer optimised whole-life contracts.

A model of the current operation and maintenance extended enterprise is created using soft systems methodology with critical value generating parameters identified.

Explanations are presented for the perception of the current extended enterprise being too expensive, slow to respond and inflexible. Future work is discussed detailing how systems engineering approaches and systems thinking can be further used to bring about a more optimised approach to operating and maintaining railway vehicles in the UK.

Key words - Systems Engineering, Value Chain, Extended Enterprise, Railway, Modelling

1 Introduction

The 2007 *'Rail Technical Strategy' (RTS)* which accompanied the UK governments *'Delivering a Sustainable Railway'* white paper outlined the aim to have "world-class reliability of both infrastructure and rolling stock" [1]. In order to achieve this, the *RTS* highlighted the need for "government and industry [to work] together taking a whole-life, whole-system cost approach in exploiting opportunities" [1].

This commitment to taking a whole-life, whole-system viewpoint is reflected in current trends by government departments, through Public Private Partnerships / Private Finance Initiatives, in which the "public and private sectors join to design, build or refurbish, finance and operate new or improved facilities and services to the general public" [2].

This whole-life approach has recently manifested itself into two tender requests made by the Department for Transport (DfT) to industry – the Intercity Express Programme (IEP) and the Thameslink programme. For the IEP, the DfT is seeking the minimum whole-life, whole-system cost for "IE Services" (the financing, procurement and delivery of the new trains and all other related services in connection with the provision of the required availability for the IEP) [3]. For the Thameslink programme, the DfT is seeking to procure a "fully financed package for the manufacture, entry into service and maintenance support of a new fleet of rolling stock" at minimum whole-life cost [4].

The whole-life, whole-system paradigm has the potential to completely change the dynamic of UK railways; provided that the industry can transform itself to deliver whole-life service offerings, maximised to deliver benefit throughout the value chain. This paper discusses the preliminary research findings of a Systems Engineering Doctorate, being undertaken at Bombardier Transportation (a railway vehicle manufacturing and servicing company), whose aim is to maximise the whole-life value of railway vehicles by optimising operations and maintenance throughout its value chain.

2 The UK railway system

A system is "a combination of interacting elements organized to achieve one more stated purposes" [5].

When viewed as a system, the (primary) purpose of the UK railway industry is to safely transport passengers and freight on time. In order to achieve this, all elements within the railway system need to work together in a holistic way –

even though the individual elements may have their own goals. For example, train operators want to maximise their profits by operating passenger services, Network Rail want to manage the existing fabric of the railway network, utility providers want to maximise their profits by providing electricity, gas and water to the railway network, etc.

The complexity within the railway system lies not in any technical aspect, although these are complicated, but in the interactions and relationships between the different stakeholders; aligning their often competing goals in order to deliver the system goal - safely transporting passengers and freight on time. This becomes especially important with the whole-life approach and requires greater co-operation and communication between all stakeholders.

The focus of this research paper is only a subset of the wider railway system, but it significantly influences, and is influenced by, the railway system. In fact, many of the interactions and relationships that exist within the railway system also exist in the operation and maintenance of railway vehicles. By modelling the relationships throughout the operations and maintenance extended enterprise, it should be possible to recommend changes to that enterprise with the aim of maximising value generation for all stakeholders (both within the extended enterprise and the railway system). These changes will affect the railway system (its structure and/or behaviour) and may drive change in that system towards greater levels of whole-life, whole-system approaches.

3 The Operation and Maintenance of Railway Vehicles

The operation and maintenance of railway vehicles is a complex process, with significant interactions amongst participants (including train operators, component suppliers and maintainers). These interactions are not uniformly defined and change depending on the type of maintenance contract between train operator, rolling stock lessor and maintainer.

Due to this complexity there is a perception that the current approach to managing the operation and maintenance of rolling stock in full maintenance contracts is too expensive and risk averse – resulting in difficulties achieving the profit margins and growth expected by senior management.

Through the use of Goldratt's Current Reality Trees [6, 7] it was felt that the core problem was that some managers make decisions to improve their short-term concerns without fully considering the long-term effects to the whole enterprise. In order to address this core problem it is necessary to tackle the problems' enablers:

1. A lack of understanding of the dependencies that exist between different business functions
2. Cost accounting rules stipulating projects/functions should always be generating a profit
3. Emphasis on localised initiatives
4. Emphasis on cost reduction

In an attempt to address the perceived core problem and better manage the complexity, a systemic analysis of the operation and maintenance of railway vehicles was carried out. This involved not only investigating the actual maintaining of railway vehicles but the extended enterprise required to deliver functional vehicles to the customer at contracted levels of availability and reliability – i.e. investigating the perceived problems across the entire value chain – from end-user back to material suppliers. The goal of this research was to visualise what the dependencies are between different business functions (problem enabler 1) and use this visualisation as a debating tool to critically analyse the impact of management policies in creating the perceived problem(s) – initiating the discussion surrounding the more sensitive problem enablers.

4 Case Study: Operation and maintenance extended enterprise

For the purposes of this research, the extended enterprise of a full UK maintenance contract was modelled. Full maintenance contracts represent a significant proportion of Bombardier Transportation's service contracts and, in any move towards long-term asset management, will be the contract type which will deliver the most value to the company.

As the perceived problem has been well defined and the scope of the work bounded to the operation and maintenance of railway vehicles and its extended enterprise; case study research was chosen as the primary method of analysis. Specifically, an intrinsic case study was chosen as the focus of the research was on the case itself [8]

4.1 Modelling methodology

The dynamic complexity of the extended enterprise; the fact that it consists of people, processes and tools all working concurrently to operate and maintain railway vehicles requires a systemic process of inquiry. Checkland's Soft Systems Methodology (SSM), developed by Peter Checkland at Lancaster University in the 1960's after the failure of using traditional "hard" systems engineering approaches on messy organisational problems, takes the "concept of a system and applies it to the process of dealing with the world" [9]. SSM not only consists of a logic-based stream of analysis, it also consists of a cultural and political stream – viewed to be a significant factor in the railway system and the operation and maintenance extended enterprise.

Although SSM has evolved during the course of its application to real-life situations over many years, the basic concept of SSM remains the same – a methodology of taking purposeful action to continually improve the current situation based on experience [10]. As such, SSM is a methodology for systemically learning about the problem situation and has been applied in this case to specifically learn about the operation and maintenance extended enterprise of railway vehicles and initiate debate on possible action to improve the situation.

The methodology, presented in Figure 1, consists of a "logical" analysis component, which identifies and analyses human activity systems, and three "cultural" analyses [11]. It can be viewed as four interdependent and interacting activities:

1. Finding out about the problem situation, including culturally and politically
2. Formulating some relevant purposeful activity models
3. Debating the situation, using the models, seeking from the debate:
    a. Changes which could improve the situation and are regarded as both desirable and (culturally) feasible
    b. The accommodation between conflicting interests which will enable action-to-improve to be taken
4. Take action to bring about the improvement

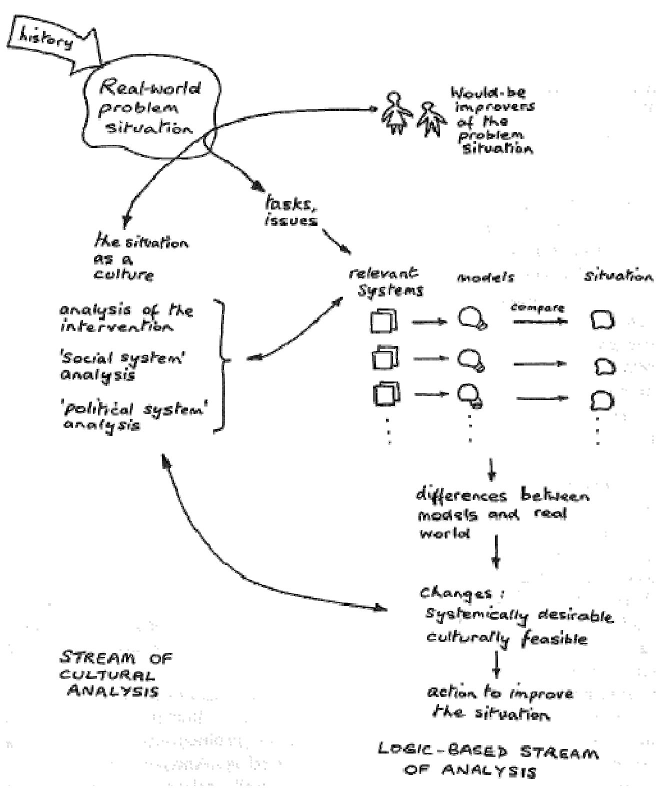

Figure 1: SSM enquiring process [10]

4.2 Applying SSM to the Operation and Maintenance Extended Enterprise

SSM can be applied in two different modes, which Checkland refers to as Mode 1 and Mode 2 [10]. Mode 1 is methodology-driven and refers to the case where a conscious choice is made to use SSM and the practitioner will move from one stage to the next sequentially. Mode 2 is situation-driven and refers to the case where the methodology has been internalised by the decision-maker and is used unconsciously in an everyday environment. The mode in which the methodology is employed in this research is somewhere in between the two. Although SSM was specifically chosen, it was used in an interactive and iterative manner in order to better understand the problem situation. This is because much of the investigation into the current extended enterprise was performed through relatively short interviews and it was impractical within the time constraints to instruct each interviewee on the methodology.

Interviews were chosen as the primary means of finding out about the problem situation. Due to time constraints on some stakeholders interviews were typically carried out on a one-to-one basis, lasting for 90 minutes each. Some stakeholders were approached on more than one occasion in order to better understand some of the contextual and situational factors involved.

Initially, the first few interviews were used to gain an overview of the extended enterprise. From these a rich picture and conceptual models were produced. These were then used in subsequent interviews as a technique for interactively eliciting greater understanding about the extended enterprise, its interactions and dependencies. The rich picture was amended and conceptual models created, amended or removed before being used in further interviews to elicit more information (Figure 2) and instigate debate.

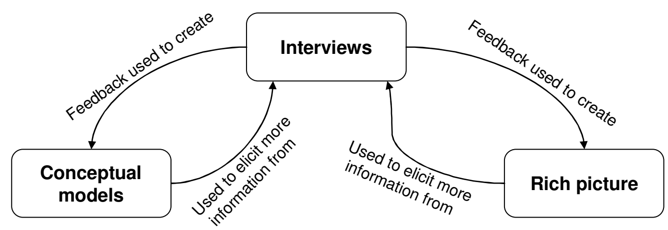

Figure 2: Iterative use of SSM to understand the extended enterprise

Over the course of the research a picture of the problem situation developed which reveals some of the complexity and relationships inherent in the operation and maintenance extended enterprise. A high-level overview of the situation can be seen in Figure 3, which has been simplified ensure the research is suitable for publication and make it more presentable. The speech bubbles within Figure 3 highlight the core concern of each function.

Throughout the research relevant purposeful systems were being identified and (conceptually) modelled as a starting point for debate and to further the understanding of the problem situation. An example of one relevant purposeful system and conceptual model is given in Figure 4.

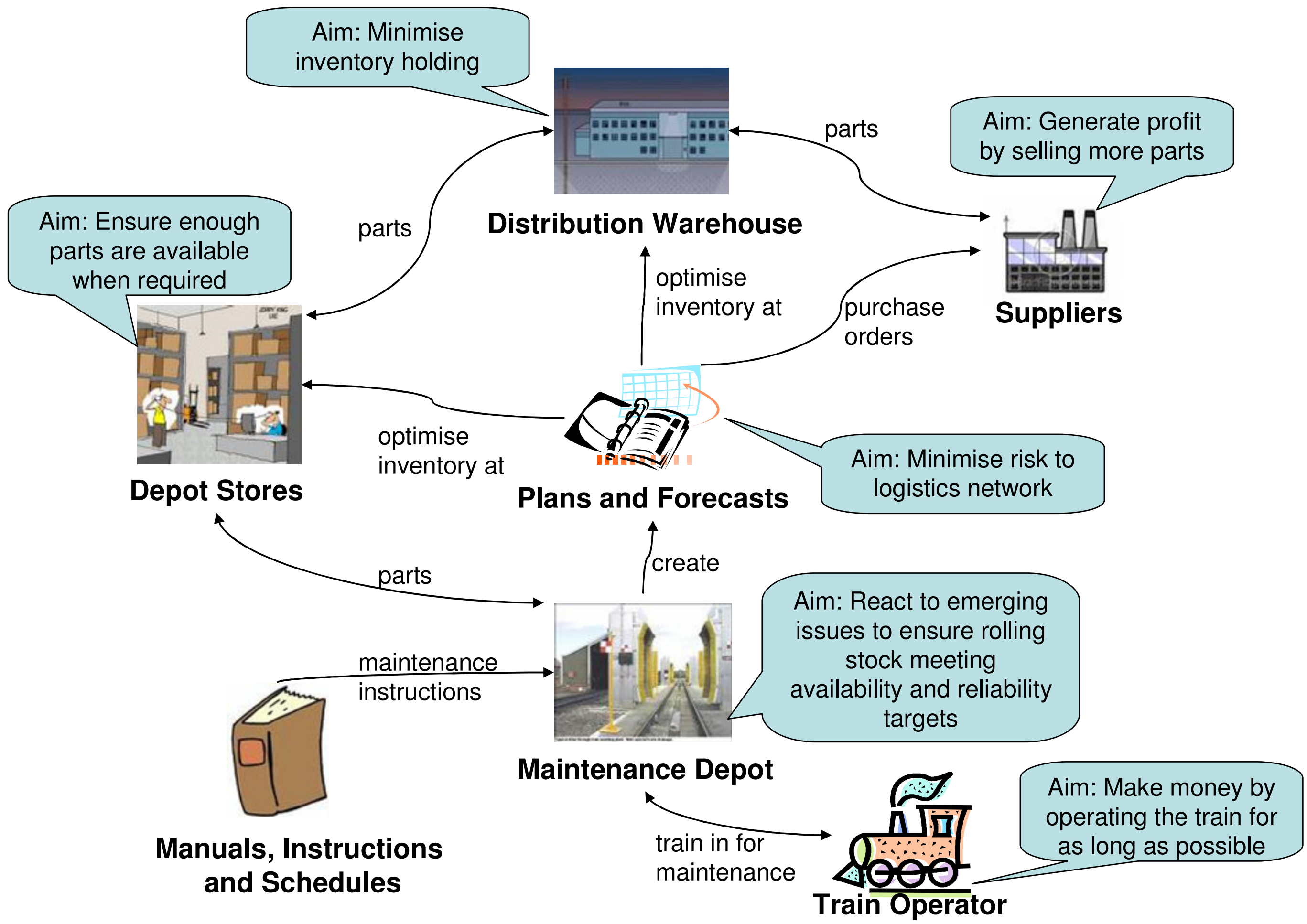

Figure 3: Rich picture model of the railway vehicle operation and maintenance extended enterprise

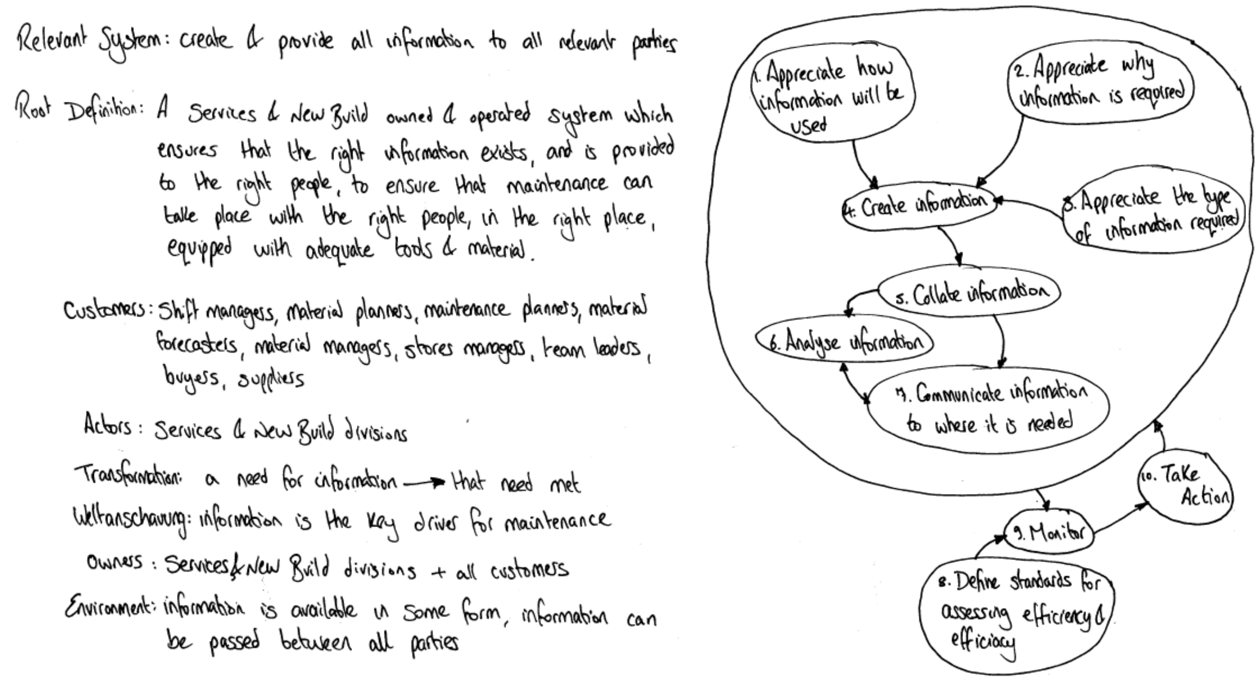

Figure 4: An example of one relevant purposeful system and ceonceptual model

During the debates it became apparent that the significance of the relationships in the rich picture model cannot be underestimated. As such, further work categorised the relationships as either:

- Physical flows
- Lines of reporting
- Information flows

The discussions following the rich picture creation and modelling allowed all participants to visualise the dependencies between the various functions in delivering the operations and maintenance service. All participants agreed that information flows are the most common type of relationship. Indeed, the physical flows (the movement of parts) are contingent upon some form of information flow taking place.

4.3 Identifying Value in the Operation and Maintenance Extended Enterprise

A value stream/chain is a sequence of activities. "Products" pass through all activities of the chain in order and at each activity value is added [12]. From this definition two questions arise:

1. What are the "products" that pass through the extended enterprise?
2. What are the value metrics in the extended enterprise?

The operation and maintenance extended enterprise can be considered an integral part of a service support value chain in which the maintainer adds value by ensuring contracted levels of availability and reliability.

From the discussions arising as part of the case study analysis, participants felt material and information are the main "products" in the operation and maintenance extended enterprise.

An unanticipated advantage of using SSM was in the identification of value metrics as an extension of formulating relevant purposeful activity models. As "no human activity system is intrinsically relevant to any problem situation" [13], the purposeful activity models give, at a high-level, an indication of one person's view of what is valuable – their perception of value is inherently linked to their perception of the system. For example, the person who views "generate a profit for the company" as a purposeful activity system sees value measured in terms of system profitability.

Using this approach and discussing value metrics with stakeholders in the debate stage led to the following critical value-generating parameters being identified:

- Quality and timeliness of information
- Quality of the relationship with suppliers
- Level of material float in the system
- System profitability
- Number of in-service failures
- Quality of the relationship with customers
- Staff turnover levels
- Number of additional revenue streams generated

While improving all of the value metrics should ultimately be reflected in improved profitability, the measures of value are not purely financial. Many of the value metrics are intangible and emerge because of the behaviour of the operation and maintenance extended enterprise as a whole.

Future work will focus on trying to further quantify the aspects of value within the service value chain (of which the operation and maintenance extended enterprise is an integral part). Once value metrics have been defined, research will focus on:

- how to measure and track whether entire service offerings are creating value for the customer;
- how value streams can be optimised to give better performance; and
- identifying new value streams within the current service value chain.

5 Conclusion

The research has shown that the maintenance of railway vehicles is a complex business process, with significant interactions amongst participants (including train operators, component suppliers and maintainers). Optimising the whole-life service performance of railway vehicles is a critical success driver to the whole-life contracts being proposed by the UK government.

The research has identified that the core problem to optimising the whole-life performance of railway vehicles is that some managers make decisions to improve their short-term concerns without fully considering the long-term affects to the whole enterprise. In order to address this core problem it is necessary to tackle the problems' enablers:

1. Lack of understand between the dependencies that exist between different business functions
2. Cost accounting rules stipulating projects/functions should always be generating a profit
3. Emphasis on localised initiatives
4. Emphasis on cost reduction

Soft Systems Methodology (SSM) has been used to help understand the operation and maintenance extended enterprise for a fleet of railway vehicles and, through the accompanying discussions, critical value generating activities, relationships and dependencies have been identified. Many of these are intangible (e.g. quality of the relationship with suppliers) and are difficult to pinpoint as belonging to any particular stakeholder: instead they are properties that the whole operation and maintenance extended enterprise system exhibit.

The research has helped all participants to visualise the dependencies between the various functions in delivering the operations and maintenance services. Information flows have been identified as the most common type of relationship and there is a perception that these flows are the main value carrier.

Future work will focus on trying to map these value metrics onto the operation and maintenance extended enterprise with the intention of determining where value is being created and lost. This will require taking an holistic viewpoint, using systems engineering approaches and systems thinking techniques, to quantify, measure and track value throughout the operations and maintenance extended enterprise to understand how value changes through time in different scenarios.

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