Case Study – Creating the WCRM Concept of Operations

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Abstract. This paper describes our experience in defining a suitable style, structure, content and set of features for the West Coast Route Modernisation (WCRM) Concept of Operations. The ability to capture the operational context of the future West Coast Main Line (WCML) railway is a critical integration activity, and key to the successful delivery of the WCRM, in particular as operational improvements contribute to a large part of the performance improvements on a railway. In the absence of guidance or standards for the production of operational concepts documents for a subject as vast and complex, we have applied rich traceability and requirements engineering best practice, with the aim to produce fit for purpose, clear and useable documentation. This paper also presents the relation between the Concept of Operations and the rest of the WCRM Systems Engineering activities, in particular its influence on the Systems Design Specification. It summarises the lessons learned and planned future developments.

INTRODUCTION

The importance of capturing operational domain knowledge. The "World and Machine" model developed in (Jackson 95) introduced the notion that a system cannot be successfully delivered without proper consideration for the environment in which it will operate. This is particularly critical in the case of a "system of systems", where the interaction and operation of the various components is very complex. An incorrect understanding of this context is one of the main causes of project failures (Hammond et al. 2001).

Requirements Engineering methods such as REVEAL® therefore recommend that domain knowledge is captured and maintained with the same rigour as the system's requirements (Hammond et al. 2001) [1].

The idea of building a suitable repository of operational philosophies and assumptions, sufficient to ensure a consistency across the components of a complex system, has been applied in defence industry for some time. It is an essential task for the stakeholder responsible for the successful integration of the delivered system. The term "Concept of Operations", often used to denote this domain knowledge information, reflects its high-level nature: it describes the "principles" rather than the "details" of the operation. However, to our knowledge, this approach has not been applied to capture the operational concepts for a whole railway.

Contribution to overall performance. The overall performance of any system is a combination of operational performance and infrastructure or equipment performance. For instance, the lap times achieved by Formula 1 teams are dependent on the track conditions, the tyres characteristics, the car design, the engine performance and reliability – all these are infrastructure and equipment factors. They also depend on the drivers' skills and fitness, the pit stop strategies, the logistical support and performance of the mechanics and pit crews – all these are operational factors. In this context, both infrastructure and equipment (a more powerful engine) and operations improvements (a faster pit stop) largely contribute to the overall performance improvements (a few seconds shaved from the lap times), but are also interdependent: both are needed to achieve the performance gains. The result of performance modelling suggest that a railway is no exception, with infrastructure improvements and new systems contributing a large part of the desired performance gains and enabling the remaining to be achieved with better and smarter ways of operating the railway.

The WCRM Context. The challenge of the WCRM is not just to deliver better infrastructure and equipment, but also to enable operational improvements for the future WCML. The WCRM Programme has a well-defined process for capturing the functional requirements for the delivery of systems and infrastructure – including some domain knowledge (Hammond et al. 2001). However the majority of the operational improvements were not explicitly defined. This presented a major risk for the programme integration.

Several reasons could explain this absence. One is the genuine complexity of describing the current and future operation of the railway, and the absence of standard or guidelines for the production of operational concept documentation for such a vast and complex subject. Another reason is the assumption that *"everyone on the programme should know these things"*. Many of the operational

[1] REVEAL is a registered trademark of Praxis Critical Systems Ltd.

improvements were in fact implicit in the programme requirements.

The WCRM Systems Engineering team was nevertheless aware that this lack of operational concept documentation would potentially result in integration issues.

DEFINING OUR OBJECTIVES

The material for the operational concepts was to a large extent available within the WCRM Programme. It needed to be collected and organised into fit for purpose, clear and useable documentation.

These "success criteria" for the documentation are largely dependant on the purpose, scope and intended audience of the Concept of Operations, and how it would relate to the other Systems Engineering and Integration activities.

There were also a number of features - such as layout, size, or the use of illustrations - which the documentation should possess or, on the contrary, avoid.

The remainder of this section expands all these objectives in detail, as they explain and justify many of the choices that we have made.

Purpose. The purpose of the WCRM Concept of Operations is to describe how the future WCML Railway will be operated. It should present the operational objectives and philosophies.

For instance, a change of maintenance strategy, how train driving will be affected by new on-board equipment, or what is the operational impact of the introduction of improved train detection equipment.

To draw out the significant differences from today, it is often necessary to provide some basic principles and a baseline description of the existing railway.

Scope. The Concept of Operations should generally present the following:

- the operational concepts for the future WCML;
- when necessary to illustrate the future, the existing WCML operational concepts;
- when applicable, the interim WCML operational concepts.

It should include the operational impact of all new technology planned for the WCML, regardless of the delivery responsibility. So it should include national initiatives on control and communication systems, as well as WCRM induced changes. In particular it should accommodate the directions proposed in (SRA 2002).

Audience. The intended audience and respective usage for the documentation are:

- Within WCRM Scope and Integration, to ensure that the system and processes developed are adequate, consistent and map to Functional Specification requirements. It is the necessary explicit baseline on which to measure future operational improvements.
- To assist key delivery teams in defining the systems and to understand the impact of new technology on the operation of the railway.
- For railway operators, maintenance contactors and train operators – to validate operating assumptions.
- To present operational domain knowledge for the benefit and induction of new staff joining the WCRM Programme from other industries.

Although the first three points are generally agreed, the fourth proved more challenging. It certainly posed the problem of finding the right balance for the Concept of Operations documentation, between the specialised technical information and introductory level content. We will explain in the "APPROACH" section how we believe we have resolved this issue.

Relation to other WCRM Systems Engineering activities. Compared to the aerospace and defence industry where Systems Engineering is quite mature, the rail industry is relatively new to this form of engineering. The Systems Engineering strategy for the WCRM aims at ensuring the effective application of appropriate systems engineering activities throughout the programme life-cycle. It is based on the traditional "V" process model, and applies and adapts the main formal engineering standards and techniques into a pragmatic implementation of systems engineering for the rail industry, suited for WCRM. Figure 1 presents a simplified view of the WCRM "V" model.

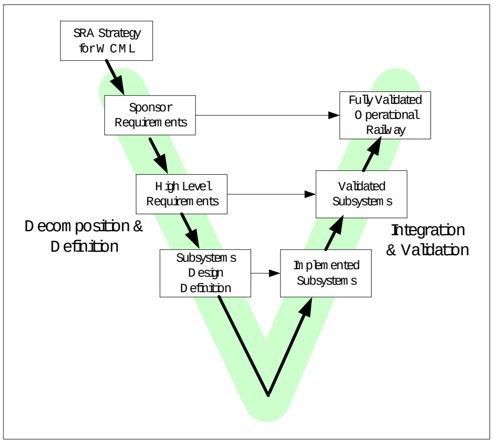

Figure 1. Simplified view of the WCRM "V" Process Model

Broadly speaking, the Strategic Rail Authority (SRA) Strategy and Sponsor Requirements set the requirements for the upgrade and the overall route performance, involving both conventional rail engineering solutions and novel developments.

During the **Decomposition and Definition** activities, these are translated into high-level systems requirements, which are in turn instantiated into location specific subsystems design specification and work remits. This is where the objective to run a Pendolino tilting train from Euston to Glasgow at speeds of up to 125mph is fulfilled by a whole range of measures, such as level crossing closures, additional power supply, enhanced track worker safety protection, up to the relocation of an individual signal. The WCRM System Engineering activities on this side of the "V" are concerned with capturing and managing requirements, and producing and justifying a design for the whole system. The WCRM requirements management and design processes apply REVEAL (Hammond et al. 2001) and rich traceability supported by the DOORS tool (Hull et al. 2002).

The Concept of Operations complements the Systems Architecture, the Performance and Safety Models as inputs to the design and therefore forms part of the Design Justification (i.e. the domain and requirements rationale behind the design choices). More precisely, operational concepts provide the domain knowledge for the design justifications. They need to be traceable in the rich traceability context, and kept and managed in DOORS. The System Architecture's UML model (Booch 99), provides the formal basis on which to build a more abstract operational model, used to structure the Concept of Operations documentation.

During the **Integration and Validation** activities, the subsystems are implemented and integrated, and ultimately validated by demonstrating that the railway meets the sponsor's requirements and is fit for purpose. Because of the complexity of the delivered railway, it is not possible to test it exhaustively, so the WCRM Systems Engineering concern on the second side of the "V" is to build the necessary confidence to support the safety and performance satisfaction arguments. There again, the operational concepts are a key input in the validation process and need to be recorded in the Satisfaction Arguments (i.e. the confidence case that the system meet the requirements and operational domain).

Features. When producing a Concept of Operations based largely on natural language documentation, one of the risks is to produce a rich conglomeration of domain knowledge, where operational concepts are present but difficult to separate from the supporting information.

Our ambition was to issue a Concept of Operations that would read well, but having a formal basis that would structure it, and allow completeness and consistency checks. The operational concepts should be clearly identifiable among the supporting text.

Maintainability of the documentation was also a high priority, since scope or technology changes are always possible in the remainder of the WCRM programme.

Requirements Engineering best practice provides some guidance that can be applied to try and achieve these objectives. The following have for instance been interpreted from applicable guidelines provided in (Sommerville 97):

- Lay out the documentation for readability;
- Make the documentation easy to change;
- Prioritise the operational concepts;
- Use language simply, consistently and concisely;
- Use diagrams appropriately;
- Uniquely identify each operational concept;
- Use a database to manage operational concepts;
- Define a traceability policy.

These are, in essence, the principles that we have applied.

Accessibility to a wide audience was another desirable feature. So for instance, when presenting the model of the railway used for the Concept of Operations, the use of system modelling notation (such as UML) was not considered appropriate, as a large part of our audience is not familiar with it or other structured or formal notations. A bespoke "intuitive" notation has been used instead. This is acceptable as the formality is provided by the underlying UML architecture, the Concept of Operations presenting a simplified view of this architecture accessible to a wider audience.

APPROACH

At the core of our approach to define WCRM Concept of Operations documentation is the realisation that operational concepts should be treated in the same way as high-level requirements.

The "Concept Box" notation that we defined encapsulates this notion and achieves our objectives of readability, ease of identification, ease of change, prioritisation, simple and concise language, unique identifier and traceability.

Figure 2 illustrates this notation. Key operational concepts are captured in concept boxes, easily identifiable from the supporting information. Current, future and interim concepts are presented together "on the same page", to give an immediate vision of the operational changes.

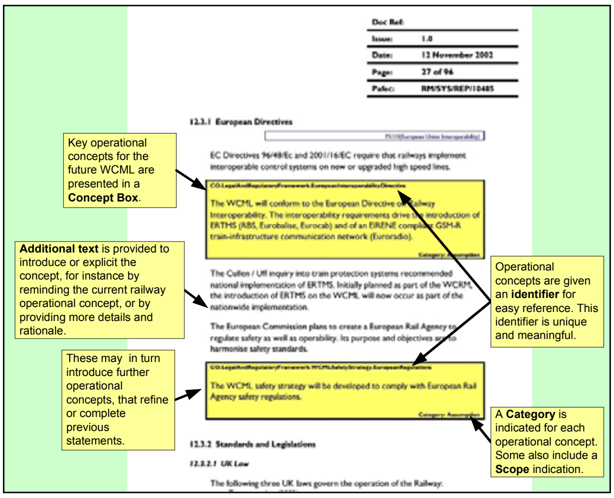

Figure 2. Concept Box notation

Figure 3 details the components of a concept box: a unique identifier, a clear and concise statement of the operational concept, and category. Each concept box only captures one concept.

CO.TrainOperation.TrainDriving.CompetenceAndTraining

The primary method for training drivers to use new equipments, procedures and respond to new lineside indications, will be through simulators. This will be completed by in-situ training using actual rolling-stock.

Category: Assumption

Figure 3. Concept Box elements

For the Concept of Operations documentation maintained in DOORS, the concept boxes are the items that are linked for rich traceability.

Operational concepts prioritisation. We are all familiar with priority attributes generally assigned to requirements, such as "key", "mandatory", "optional" or "desirable". We transposed this to operational concepts by assigning them a **category**. Three **categories** are currently distinguished:

- **Concept** – denoting that there are already strong indications that the future systems and processes will be operated in the manner stated.
- **Assumption** – expressing operational hypotheses about the future WCML. If confirmed, assumptions can be moved to the "Concept" category.
- **Aspiration** – suggesting an ideal operational concept, which may not be immediately achievable, but is still essential to set the desirable operational targets.

When required, the **Scope** of the operation concept is also indicated after the Category. Typical scope indications would be for instance:

- Tilting trains only;
- TMS fitted trains only;
- Freight trains only;
- NMC control areas only;
- Etc.

When no scope is indicated, the operational concept applies generally.

Content Balance. As our objectives in term of audience were slightly contradictory, our approach was to split the Concept of Operations documentation in two documents:

- the Railway Level Concept of Operations (RLCO) – containing the high level operational concepts, and written for a knowledgeable audience.
- the General Railway Operation Principles (GROP) – supporting the first, providing more detailed railway technology and operational knowledge, written for an audience with little or no railway knowledge.

The structure of the second directly mirrors the first. For instance, the RLCO section regarding train protection and warning systems contains several concept boxes, one of which states that the AWS system will continue to be used. The corresponding section in the GROP details on several pages the principles and operation of AWS.

This organisation has the advantage to satisfy both audiences, while keeping the size of the documents to a reasonable and manageable size, key to making them useable and maintainable.

DEFINING THE STRUCTURE AND CONTENT

Abstract model for Railway Operation. Having established a very long list of topics that ought to be covered in the railway Concept of Operations, we needed to organise these in a (preferably) logical structure – like a generic framework for the operation of the railway.

If we consider that the purpose of the railway is to run a train safely and punctually from A to B, we can distinguish the main groups of activities:

- all the day to day activities concerned with **running** the train, such as driving the train, setting the points and signals, or managing stations and passengers.
- a number of long term **planning** activities, such as setting performance targets or producing a timetable (the latter starts 13 months prior to the introduction of the timetable – the specification up to 5 years prior).
- a number of short or long term **maintenance** activities, necessary to keep the trains running safely and punctually, such as re-profiling the track or reviewing the performance.

This suggested the high level "Plan – Run –

Maintain" structure presented on Figure 4. Each group is composed of "traditional" operations activities, based on the operating boundaries set by the privatisation of British Rail. For instance, the infrastructure maintenance is the responsibility of Network Rail, while the traction and rolling stock maintenance is the responsibility of the leasing and train operating companies.

Although this model's main purpose is to provide the documentation's skeleton structure, we ensured that it mapped onto, and was consistent with, the Systems Architecture UML model.

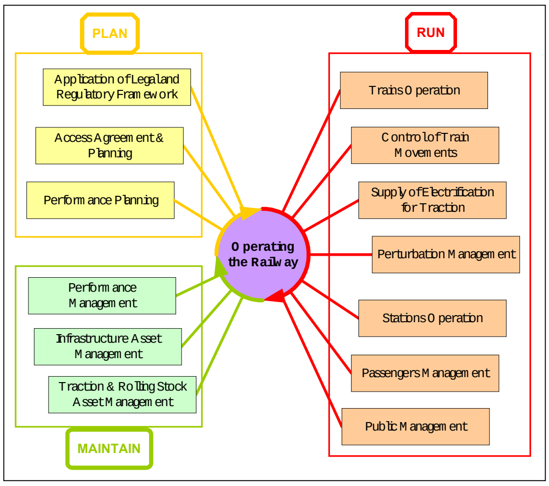

Figure 4. Railway Operation Model

Further decomposition. The model on Figure 4 provides our high level structure. Each activity is in turn refined using diagrams similar to "mind map" diagrams, showing the logical decomposition of an activity, and what equipment or items are "used". Again, this model is mapped onto the underlying UML model. Figure 5 shows the decomposition of the "Train Operation" activity identified on Figure 4.

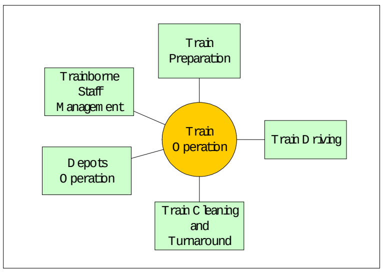

Figure 5. Train Operation activity decomposition

For complex activities, such "Train Driving", another level of decomposition is required (Figure 6).

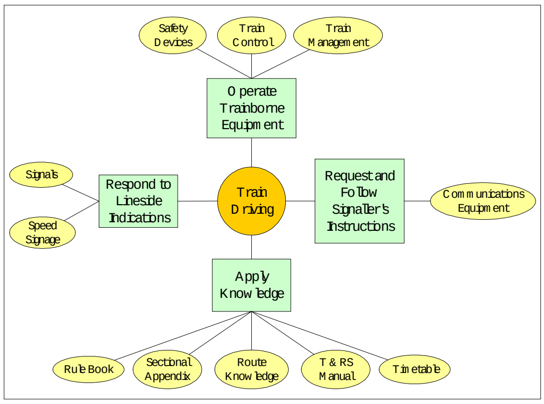

Figure 6. Train Driving activity decomposition

The decomposition diagrams were found to provide a visual checklist for completeness: a railway specialist might for instance remark that when requesting a signaller's instructions, a driver will also use location information – such as the identification number on a signal post telephone or on a signal. They were also used as a starting point to fill in the concept boxes.

Filling the (concept) boxes. Having established a well structured taxonomy of operational concepts, the remaining task required to use available material and railway operation specialist knowledge in each domain to fill in the concept boxes and supporting documentation.

A traditional method for elicitation of operational domain knowledge is by producing scenarios or "day in the life" descriptions. The following were considered for this work: train driver (both passenger and freight), signaller, maintainer, and passenger. They should have been produced in several variants for the current, future and interim states of the railway, and for each, record both normal and degraded operation modes. Having produced the "day in the life of a signaller" description, we concluded that the effort involved in producing these descriptions, even at a high level, was not an efficient use of our resources. In the signaller's case, 3 operational concepts were ultimately extracted from the 25 pages of descriptions produced – which were not even a complete set.

Our approach was to use the taxonomy of activities, items and equipments defined by our decomposition diagrams, to systematically identify the concepts that needed to be documented. This was achieved by applying a simple checklist: For each activity, item or equipment, we would apply the following simple checklist: Are they any concepts relative to:

1) unchanged operation of an existing item /equipment - for instance, the fact that the Automatic Warning System (AWS) will still be in use;
2) new or modified utilisation of an existing item / equipment – for instance, the fact that although the working timetable will still be

used as currently, it will be adhered to with much more discipline.

3) use of a new item / equipment to perform an existing function – for instance GSM-R Cab radios will replace Cab Secure Radios.
4) new function carried out by a new item / equipment - for instance, new speed boards used to display enhanced permissible speed, applicable to tilting trains only.

The corresponding operational concepts, either elicited from specialists, or extracted from existing documentation, were then documented in the concept box style.

Adding a summary view. The resulting RLCO document is concise and well structured, however, one view seemed to be missing: one that would summarize – for instance on a single diagram – the operational changes from the point of view of a driver, a signaller, a maintainer, etc.

As with the other diagrams used in the Concept of Operations documentation, the concern is more on using an intuitive rather than formal notation.

Figure 7 shows an example of concept summary diagrams that was designed to address this.

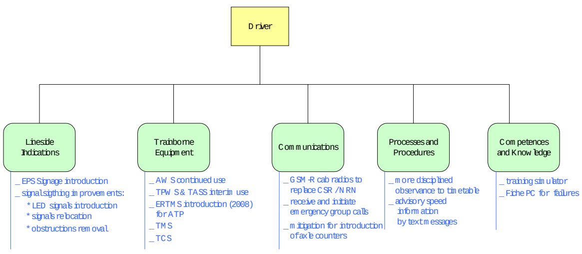

Figure 7. Driver concepts summary diagram

It was also important to summarise changes in the interaction between the various operational stakeholders. Figure 8 shows an interaction summary diagram for Driver and Traction and Rolling Stock Maintainer.

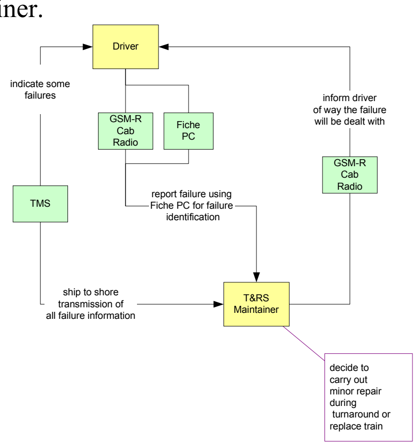

Figure 8. Driver – Maintainer interaction concepts summary diagram

SUMMARY AND CONCLUSION

Lessons Learned. The Concept of Operations documents were developed over a period of 6 months, during which our objectives were refined and our approach shaped into what is presented here. Some of the ideas were not immediately evident, and were determined by evaluating "strawman" documentations against our evolving set of criteria. So the first lesson is certainly that, if we had to produce another Concept of Operations documentation, we would start from the approach described in this paper. It is likely that, even for less complex systems, a similar approach would bring some benefits. The following are the key elements of the approach that we would retain:

- the "concept box" presentation, which encapsulate many of our objectives: readability, maintainability, traceability and prioritisation;
- the presentation of the current and future vision side by side "on the same page", which provides a better view of what the changes are than if they were exposed in different sections several pages apart or in different documents;
- the "two tier" documentation split, to cater for audience with different knowledge of the subject;
- the use of an operation model and "mind map" activity decomposition to structure the document.
- that scenarios or "day in the life" descriptions are not appropriate to elicit high-level concepts of operation.

Future Developments. The documentation of operational concepts is seen as a continuous stream of activity within the WCRM Systems Engineering.

Although the first issue has been well received, it is also acknowledged it has not been put fully to the test: it is currently being used in the design justification, but still has to be used for the satisfaction arguments. Gaps and errors in the operational concepts are no doubt present, and the documentation will need to be maintained to reflect the programme changes. The WCRM Railway Level Concept of Operations will also need to support subsystems operational concepts documentation activities.

All these future developments will provide the real test that we have a maintainable and fit for purpose documentation.

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BIOGRAPHY

Jérôme Loubersac is a Chartered Engineer who has 10 years experience in all stages of the system and software development lifecycle of high reliability and safety-critical systems. He has an excellent knowledge of formal methods and requirements engineering, in particular applying Praxis Critical Systems' REVEAL® method. Jérôme was responsible for the production of the WCRM Concept of Operations documentation.

Brian Halliday is Network Rail’s Systems Engineering Manager for the West Coast Route Modernisation Programme. He has over 30 years ‘hands-on’ experience in the field of systems engineering. During the early seventies he worked as Reliability Engineer in the Systems Design Group of Hawker Siddeley Aviation and was involved in a wide range of safety, reliability, maintainability, and support cost studies on a new generation of civil aircraft designs. Subsequently, he worked as RAMS Manager for a major Defence Prime Contractor and was responsible for those aspects on all of the Company’s development projects, many involving complex high integrity systems. He also provided specialist support to customers in the Defence, Aviation, Nuclear and Rail sectors. In 1997 Brian joined Railtrack PLC as Systems Engineering Manager within the West Coast Route Modernisation project where his responsibilities include Requirements Management, System Definition, Systems Effectiveness Modelling and Verification & Validation.