Why Brownfield Re-signalling Projects always require a Transition State

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SUMMARY

This paper delivers a process of changing the train control system of an operating railway (a brownfield resignalling project) whilst maintaining resilience during the difficult period of change (the transition period).

Conventional resignalling projects have traditionally included a transition state. This would typically involve new signals being erected in advance of the changeover weekend and covered with a hood and a white cross, and pre-installing wiring at interfaces.

As signalling technology has moved onto the train, the changes required when replacing signalling technology have become more complicated. The number of players interacting with the signalling system has increased, and the commercial arrangements between those players has become more complex. The result of this is that the ability to change the whole system over one weekend has reduced.

There are only two solutions to this challenge: one solution is to introduce a significant closure of the whole system (typically three months or more); the alternative is to break the change into a number of steps, each of which is manageable over a weekend. This introduces temporary operating states (Transition States) between the current state and the final state but reduces the overall project transition risk.

This paper explains in further detail the need for such Transition States. It concludes that change should be introduced in as few complex stages as possible, and that each stage should carry just less project risk than the maximum risk that the organisation is prepared to accept.

1 INTRODUCTION

Brownfield signalling projects are about making changes to an existing railway signalling system. In this paper, the term 'signalling system' is used in the wider context that includes all technical elements required for the safe and efficient control of trains, including, where required, telecommunications, onboard systems, and traffic management systems.

Projects are referred to as 'brownfield' when there is already an operating rail system in place. This places many constraints on the implementation of changes because trains 'must be kept running', and the system's users are already familiar with existing methods and systems of operations. The other extreme is a 'greenfield' project in which there are not already any existing operations. Greenfield projects are much simpler to place into operation because they can be tested without the constraints of having to work around existing operating times, procedures and equipment.

Users, in the context of this paper, are the direct users of the signalling system. They are principally the train drivers, signallers (network controllers), and maintainers (including rolling stock maintainers if signalling equipment is fitted onboard trains). The term 'users' does include any other parties that directly come into contact with part of the system (e.g. road traffic users at a level crossing).

Risk is a significant factor in the implementation of railway signalling projects. In this paper, safety risk is considered separately from project risk: the management of the former is well defined in the international CENELEC standards; whilst the management of project risk in the railway environment is not well defined in international standards.

2 TRANSITION STATES IN BROWNFIELD PROJECTS

2.1 What are Transition States?

When making major changes to existing railway signalling systems (hence as part of a brownfield project), it is usually unacceptable to close the rail network for the duration of the implementation period because this could last for several months. Therefore, implementation will be progressive, occurring in parallel with existing operations. As implementation continues, some changes to the current operation may start to be implemented, affecting the system's users. If a change affects a user, then the signalling system is considered to have changed to a different 'state'. That state may be the final state of the project, or it may be an in-between state that forms part of the path to the final state. Any states *between* the initial state and the final state are referred to in this paper as 'Transition States'.

Transition States can exist in many different forms, but they should always be regarded from the point of view of the user. Some examples of transition states are as follows:

- As seen by the maintainer: new equipment that is not yet in service, but is installed alongside existing operational equipment, possibly sharing power supplies, and with changeover mechanisms in place to allow for a rapid changeover
- As seen by train drivers: new signals erected but masked alongside existing signals; or cab displays relocated to make space for an additional cab display that is not yet in use
- As seen by the signal controller: new infrastructure that is not yet in use, shown on the control centre signalling control system diagrams
- As seen by multiple users: a new crossover installed in the track, wired, locked out of use, but detected in the existing signalling system and indicated by the signalling control system.

2.2 Costs Increase with the Number of Transitions

There is an optimum number of transition states for any project.

The direct costs of a project increase approximately linearly with the number of transition states, as shown later in this paper. The overall project risk decreases non-lineally with the number of transition states because breaking a change into multiple smaller changes reduces the overall risk. This is also shown later in this paper. The combination of the two are shown graphically in Figure 1: Project Cost versus number of Transition States.

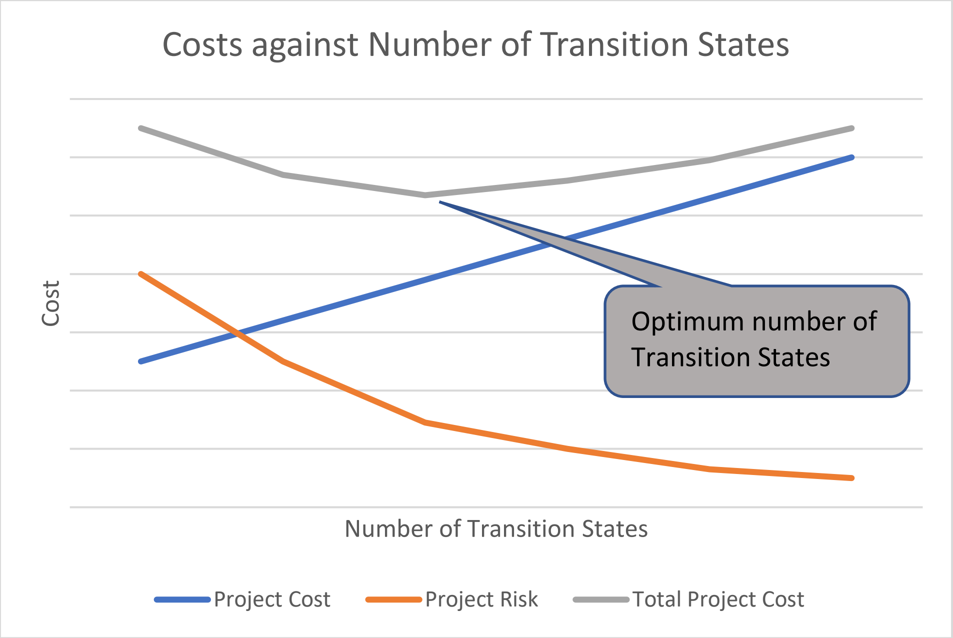

Figure 1: Project Cost versus number of Transition States

This paper presents a model for determining the optimum number of transition states to enable a project to be designed and planned to achieve the overall lowest risk-adjusted total cost.

2.3 Why are Transition States becoming more critical?

As signalling technology has moved onto the train, the changes required when replacing signalling technology have become more complicated. The number of players interacting with the signalling system has increased, and the commercial arrangements between those players has become more complex. The result of this is that the ability to change the whole system over one weekend has diminished.

There are only two solutions to this challenge: one solution is to introduce a significant closure of the whole system (typically three months or more); the alternative is to break the change into a number of steps, each of which is manageable over a short closure (typically a weekend for a passenger railway). This latter solution introduces temporary operating stages ('Transition States') between the current state and the final state, but reduces the size of the change of each stage.

2.4 Operational Restrictions

Transition States often have operational restrictions associated with them. These are administrative controls to manage risks not mitigated by the system. For the final state, such operational restrictions might not be acceptable. But Transition States are present for only a short period of time and therefore the exposure to such risks is relatively short, so the use of administrative controls may be justifiable.

However, such restrictions do still carry risks. In the case of Transition States, it is not always straightforward to assess how high such a risk is. The Transition State may be a state not previously present, and one with which the railway is not familiar. Administrative controls rely upon staff training. But when the Transition State is designed, the training will not yet have been conducted, making it difficult to determine in advance how effective the administrative control is going to be. Therefore, railways should be particularly cautious around any operational restrictions associated with Transition States.

Much effort is required to reduce the risks surrounding Transition States to be as low as reasonably practicable, and to demonstrate that this has been achieved. This is another reason for reducing the number of such states, and why project costs increase significantly if there are multiple Transition States.

2.5 Maximum Size of a Change

There is a maximum size of change that an organisation can undertake in a single stage. If a change larger than this maximum is attempted, then it is unlikely to be successful. This maximum applies to each individual stage, and varies from organisation to organisation. It depends on many factors, including the organisation's:

- Size
- Culture
- Maturity
- Industrial Relations
- Experience/organisation in implementing projects
- Risk appetite

If a change is larger than the organisation's accepted maximum, then it needs to be broken down into one or more smaller stages. This is shown in figure 2: Changing States.

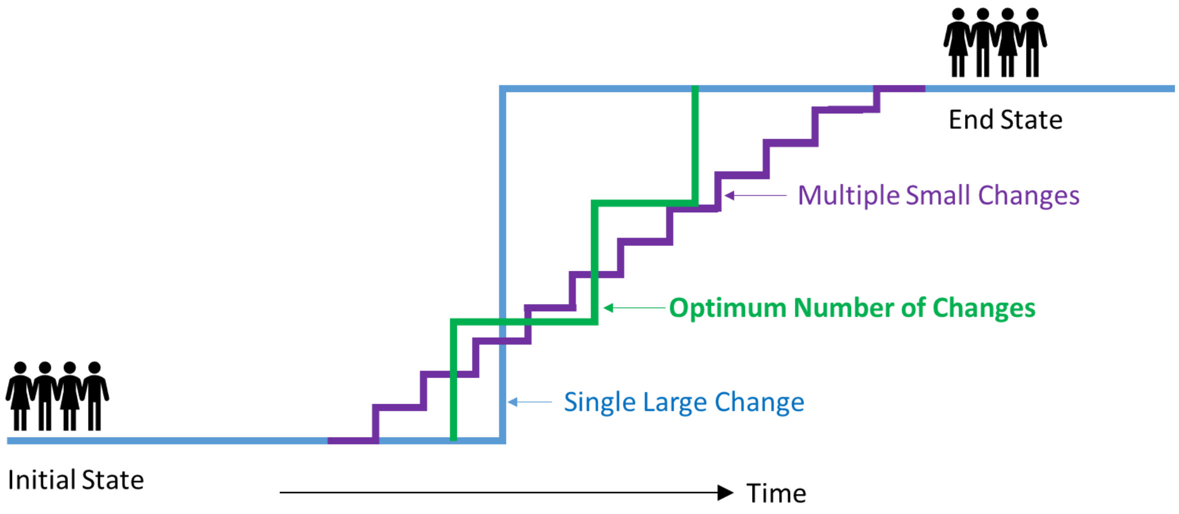

Figure 2: Changing States

2.6 Why Conduct a Resignalling Project?

A signalling project is undertaken when the expected benefits (both financial and non-financial) of a change outweigh the expected costs of the change. A signalling project includes all the works (both physical and non-physical) that are required to make the change within all impacted organisations.

Both benefits and costs are influenced by the project's transition strategy. These impacts are considered in more detail later in this paper, but the areas in which costs and benefits are particularly impacted by the transition strategy are considered in this section as this sets up a framework for reviewing the impacts of change:

2.6.1 Benefits influenced by Transition Strategy

Delay (or acceleration) of the overall project timescales has a major impact on the value of project benefits because benefits generally do not start to accrue until the time of the project's completion, whilst costs are incurred prior to completion. Increasing the number of stages in a project's implementation is likely to delay the project's planned completion.

Complexity of the delivered systems can erode project benefits as increased complexity of the delivered solution may lead to greater than expected maintenance and/or support costs during the lifetime of the delivered solution. More complex systems generally require a greater level of on-going training of users and maintainers.

2.6.2 Costs influenced by Transition Strategy

The major elements of costs heavily influenced by a transition strategy are the following:

- Temporary works (i.e. works that do not form part of the ultimate solution) are generally required for a transition state. These can be considerable in cost if they require temporary signals and temporary interlockings.
- Systems assurance work is required for each stage of a project to demonstrate that all safety risks have been reduced so far as is reasonably practicable before that stage enters revenue service. A greater number of stages will generally lead to greater systems assurance costs due to the increased number of stages, even though the complexity of each stage may be reduced.
- Closures and shutdowns of a rail network are both expensive to implement and are negatively perceived by passenger and freight customers. The choice of transition strategy is likely to have an impact on the number and size of closures necessary to implement the project.

- Users of systems (e.g. train drivers, controllers, maintainers, etc.) require training for any operating state that they are required to support. They also require time to assimilate the training. A path with a greater number of states, particularly if they are relatively complex, will cost more in terms of training, and take longer, than a simpler path.

These additional costs have a high overhead per stage, i.e. there is a high fixed cost from introducing an additional stage, irrespective of the contents of that stage due to the costs involved in systems assurance, closures and user training being largely fixed and not dependent on the size of the stage.

2.7 Signalling Application Model

In order to discuss changes, it is useful to break down the different elements of a signalling system into three layers, as per Figure 3: Signalling Application Model. This then allows the impacts of changes to be considered as they affect the different parts of the signalling system.

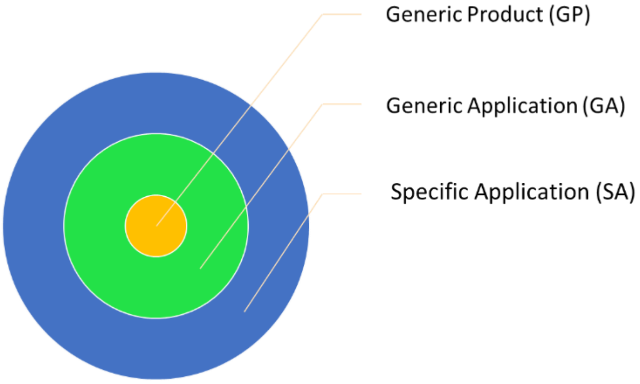

Figure 3: Signalling Application Model

This model is consistent with the international CENELEC standards for railway applications EN50126, EN50128 and EN50129. Whilst these standards are aimed at software solutions, the model is also applicable to relay-based interlockings.

The Generic Product (GP) refers to the core hardware (including the operating system for software-based solutions) that operates the signalling system. Examples of subsystems containing such hardware include interlockings, object controllers, radio block centres and zone controllers.

The Generic Application (GA) refers to the signalling rules that a railway applies. These may be implemented in software, by data templates, or by sets of standard drawings. The GA only needs to be developed once for each railway's operating rules for each GP.

The Specific Application (SA) refers to the coding of the actual railway track layout and performance of the rolling stock. The SA is the geographical representation of the railway and the parameterisation of the rolling stock. This is in the form of data for computer-based systems, or wiring diagrams for relay-based solutions.

The use of the Signalling Application Model is recommended for all signalling projects for the following reasons:

- The layers are each separately defined, with well-defined interfaces and boundaries, allowing alterations to each to be managed and controlled separately
- Alterations to the layers must be completed and tested working from the inside outwards. Each layer should be completed and tested in its own right prior to commencing work on the next layer because changes to inner layers may impact outer layers, but not vice versa.
- The skills required for work on each layer are different.
- Work in such a manner supports structured safety assurance in accordance with the CENELEC standards.

2.8 Changes to a Signalling System

The complexity of changes to a signalling system can be categorised by which of the layers of the Signalling Application Model are affected. Changes can impact any one or several of the layers. For example, a geographic change to the track layout will only impact the outer (SA) layer. A change to signalling principles will only impact the middle (GA) layer. A hardware replacement with compatible hardware may only impact the inner (GP) layer. Many signalling projects impact more than one layer. In general, a change to one layer will affect layers outside of that layer, and not layers inside it: considerable effort is required to make changes to inner layers without impacting the next outer layer. For example, upgrading an interlocking hardware platform (the GP) without changing the application data (the SA) requires much analysis to demonstrate that there is no risk of inadvertent changes to the logic such that a principles re-test is not required.

It is useful to classify signalling changes by their complexity as this affects the optimum method for managing such changes. This paper introduces a classification of changes as being either Simple or Complex:

2.8.1 Simple Changes

Simple changes only impact one layer of the Signalling Application Model. Whilst they may impact more than one group of users, they are generally manageable by existing processes within the impacted organisations as this type of change is almost ‘business as usual’. An example of a Simple Change is signalling alterations to support track changes, even major track changes, but with the signalling principles being unchanged; this would be a change just to the Specific Application (SA).

Simple Changes, and multiple Simple Changes in succession, are manageable by a business using existing business processes. Therefore, such changes are not of major concern when considering transition states.

2.8.2 Complex Changes

Complex Changes impact two or more layers of the Signalling Application Model. They impact more than one group of users and are generally not manageable by existing processes within the impacted organisations. Such changes are not ‘business as usual’. They do not happen very often, so businesses do not develop generic processes to deal with them. The reason for the complexity is that the inter-play between the two layers that are being changed is hard to predict and often leads to unforeseen consequences.

An example of a Complex Change is signalling alterations to support track changes that also require a change to the signalling principles. This would be a change to the Generic Application and the Specific Application. Driver and signaller training would require special consideration due to the impact of the change to signalling principles, requiring changes to the operational rules as well as familiarisation with the changed infrastructure.

Complex Changes carry a high level of project risk. Their impact on stakeholders is not straightforward. The interplay between the alterations to the two layers may lead to unintended consequences. There may be impacts outside of the project area due to changes to the GA from a desire and/or need for the GA to be consistent across a network. If the implementation of the change during the changeover period goes wrong, there may not be an immediately available fall-back state. For these reasons, there is a maximum size of Complex Change that an organisation should be prepared to implement in a single stage.

Complex Changes require careful consideration and assessment, from all impacted users’ points of view. These are the changes that require particularly careful managing when considering Transition States.

2.9 Summation of Project Risk

In classical risk theory, the sum of two risks (named A and B) is the mathematical addition of the two risks:

$$P(A\ or\ B) = P(A) + P(B) - P(A\ and\ B)$$

If risks A and B are independent, then:

$$P(A\ and\ B) = P(A)\,.\,P(B)$$

As $P(A)$ and $P(B)$ are usually both small, $P(A\ and\ B) \approx 0$ so long as A and B are independent, which leads to the general conclusion that independent risks can be arithmetically added together:

$$P(A\ or\ B) = P(A) + P(B) \text{ when } P(A) \text{ and } P(B) \text{ are small and independent}$$

In the case of project risks associated with railway signalling projects, this does not usually hold true because the risks are generally not independent. Even events that would appear independent become interlinked if they share mitigations. Therefore, the sum of two risks is less than their arithmetic addition:

$$P(A\ or\ B) < P(A) + P(B)$$

This is applied to the advantage of railway operators by combining several otherwise independent changes into a single shutdown and allowing contingency in both time and management effort such that the probability of unforeseen events in either change being unresolvable in the allocated time is very low.

That the overall risk is reduced by combining a number of smaller changes into one larger change for implementation supports the conclusion that projects should be implemented in the smallest number of stages possible.

2.10 Choice of Paths

For all changes, other than the simplest of Simple Changes, there will be more than one possible path from the current state to the desired state. The following process is recommended for selecting the optimum route:

- Understand the project objectives, including their relative importance (e.g. the cost versus time conundrum)
- Brainstorm with the key impacted parties to obtain the list of major possible paths
- In each possible path:
  - Identify the Complex Changes
  - Determine whether the project risk of the Complex Changes is acceptable to the organisation
  - Discard any paths which contain Complex Changes of too high a project risk
- Assess the remaining paths against the project objectives
- Select the path with the highest score

2.11 Assessment Factors

When comparing different paths, the criteria to be used should be those of the project objectives. However, project objectives tend to be too high level to be useful at this level. Therefore, it is suggested that these are disaggregated into a set of factors that are linked to the project objectives, but are more directly applicable to the signalling elements of a project. They could include:

A. Safety – different paths may have different safety impacts due to temporary methods of operations and/or different timescales for realising any safety benefits of the project

B. Number of stages – more stages cost more and take longer, particularly with Complex Changes

C. Do the major stages have a fallback option if that stage has problems?

D. Dependency upon stakeholders over which the project has little control

E. Industrial Relations impacts

F. Impacts on other stakeholders

G. Resource requirements, particularly of critical resources

H. Customer and public perception

I. Impacts on project benefits

J. Project cost

2.12 Project Risk Management

Even with the rigour of the above process, unexpected external or internal factors can de-rail the selected plan. If such events occur, it may be necessary to change track, either significantly or slightly. The possibility of changing track should be considered as part of the possible project risk mitigations – once a route is selected, it is not necessary to stick to that route at all costs. What is important is that the selected route is well considered, and that all parties understand the chosen route and the project risks involved.

2.13 The Optimum Number of Stages

An implementation path with a larger number of stages will generally cost more and take longer to implement than a path with a smaller number of stages. This factor also leads to implementing projects with the minimum number of stages, and increasing the amount of change introduced by each stage.

An organisation has a maximum amount of risk that it considers tolerable. This maximum applies to each stage, because once a stage is completed, the risk has passed. Therefore, the amount of change introduced by each stage should not exceed this maximum.

Determining the optimum number of stages for the implementation of a project is a balance between cost, time and project risk, which leads to the following conclusion:

A project should be implemented with the ***minimum*** number of stages such that the project ***risks*** associated with ***every*** stage are acceptable. This may involve ***increasing*** the size of each stage so that the project risk of each stage is ***just below*** the organisation's level of risk tolerability.

3 CONCLUSION

The overall objective of a resignalling project is to change from the existing operating state to a new operating state in order to realise safety and/or business benefits. Making the whole of the change in one step overnight is not feasible on a brownfield (operating) railway. For Complex Changes the project risk would be too great. Whilst it may be practicable to replace the whole of the signalling technology over one weekend, it is not feasible to make major changes to multiple staff working practices, safe operating procedures and rail timetables over that same weekend. The risk of failure would be too high, both in probability and consequence.

This paper has proposed a strategy for assessing the change required, and for selecting the optimum path for implementing the overall change as a series of smaller, more manageable changes. After each change, the system is in a Transition State as it transitions to the final state.

Selecting which of the possible paths is the optimum path depends on the priorities of the rail organisation. This paper has shown that the optimum path is likely to be the path with the smallest number of complex changes, but where the project risk of each complex change is just below the tolerable risk level of the railway organisation.

4 ACKNOWLEDGEMENTS

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