

DELIVERING COMPLEXITY IN THE RAIL INDUSTRY – A SYSTEM ENGINEERING APPROACH TO PROGRAMME MANAGEMENT

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1. SUMMARY

The infusion of technology into modern railways has introduced a complexity that requires new techniques in delivery. Management of technically rich projects themselves require a structured System Engineering approach to controlling the engineering aspects. However it is not just the infusion of technology that makes these projects challenging; there are other elements like the management of logistics, multiple stakeholders, safety and operational demands that add to the challenge. A combination of System Engineering and Programme Management Techniques is proposed to bring order into managing the delivery.

The ultimate output capability of the project must first be established; the scope is then broken down technically, operationally, contractually and programmatically, and then re-assembled around common goals covering disciplines and stakeholders. The programme schedule is established, stages of delivery are identified by key delivery points which are then defined by their physical, functional, performance and operational characteristics. A graphical representation helps to give a clear understanding of the delivery strategy. This is then used to communicate the plan and to monitor progress. The process has been employed extensively in the UK, mainland Europe and the Middle East.

2. INTRODUCTION

Railway infrastructure is a unique mix of old and new, performing a task that is taken for granted by the travelling public. Delivering projects in this environment means to deliver a transformation with minimum disruption, almost by stealth.

Railways are growing increasingly complex with the infusion of modern technology and the changing nature of the rail industry as a whole; the increased reliance on rail travel has generated an unprecedented intensity of service reliability demands, thus challenging technology to deliver more benefits. This complexity is increased when projects are on brownfield sites, adding the need to maintain continued operations, adapt to older technology and to migrate operations from old to new in a seamless way.

The environment within which the project is delivered can also be a major contributor to the complexity. This environment often includes multiple stakeholders with diverging priorities, tight schedule demands with limited access to the railway, tight budget constraints with numerous scope changes, the need for organizational transformation to make the best use of the new technology and most of all the PEOPLE involved in the delivery.

The UK's 2011 Rail Value for Money Study [1] into escalating costs of major infrastructure projects in the UK concluded that up to 18% savings could be achieved by avoiding over-engineering the

solution. An additional 30% could be saved by employing best practice programme management techniques. This paper will demonstrate how the application of system engineering principles to the programme management of complex rail projects can harness most of the potential savings, whilst delivering the desired capability on time, within budget and minimum disruption to the travelling public....the holy grail.

This paper will outline a methodology for managing such complex rail projects and will use case studies (Victoria Line Upgrade and Thameslink Programme) to illustrate the tools and techniques developed to successfully manage such complexity.

3. SETTING DOWN THE CASE

3.1. The Challenges

For the travelling public, rail is an antiquated form of transport with a low tech image. This has all started to change in recent years, where rail has experienced a global renaissance. This has resulted in a large number of new build railways covering high speed and metro in countries and cities where such infrastructure didn't previously exist, as well as in countries with an established railway network. In addition there are upgrades to adopt modern technology and extensions to existing lines and networks.

To most, Greenfield projects would appear ideal; after all, we all long for a clean sheet of paper, to not have to deal with the wrongs of yesteryear.

But these are usually in places where the processes, talent and knowledge of railway systems don't exist. The challenge is to train local professionals and generally push the boundaries of what was previously possible. These could be new types of technology like moving block signalling, higher speed rolling stock, electrification, new types of traction power feeding, maglev, inductive systems etc. but also those of new legislation, and even having to draft and achieve new quality or safety standards. So besides new technology, complexity in a Greenfield project could involve the lack of an established environment

On brownfield projects the challenges are those of coexisting technologies, fixed operational methods and the need to minimise disruption during delivery. This includes adapting new to old, access constraints, safety case regimes, engineering standards, working on live railway, migration to new, mixed fleet running, reliability growth etc.

3.2 What is Systems Engineering?

The International Council on Systems Engineering, INCOSE defines Systems Engineering as:

'An interdisciplinary approach and means to enable the realisation of successful systems. It focuses on defining customer needs and required functionality early in the development cycle, documenting requirements, then proceeding with design synthesis and system validation while considering the complete problem:

- Operations
- Cost and schedule
- Performance
- Manufacturing
- Training and Support
- Test
- Disposal

Systems Engineering integrates all the disciplines and specialty groups into a team effort forming a structured development process that proceeds from concept to production to operation. Systems Engineering considers both the business and the technical needs of all customers with the goal of providing a quality product that meets the user needs.

3.3 What is Programme Management?

The International Association of Project and Programme Management defines both programme and project management. See <http://www.iappm.org/concepts.htm>.

Programme Management: Programme management is the active process of managing multiple global work streams or projects which need to meet or exceed business goals according

to a pre-determined methodology or life-cycle. Programme management focuses on tighter integration, closely knit communications and more control over programme resources and priorities." [IAPPM-2003]

Project Management: Project management is the centralised management by an individual to plan, organise, control and deploy key milestones, deliverables and resources from conception through retirement, according to customer goals. Often project managers are skilled to use specific templates and techniques to manage through the preferred project life-cycle." [IAPPM-2003]

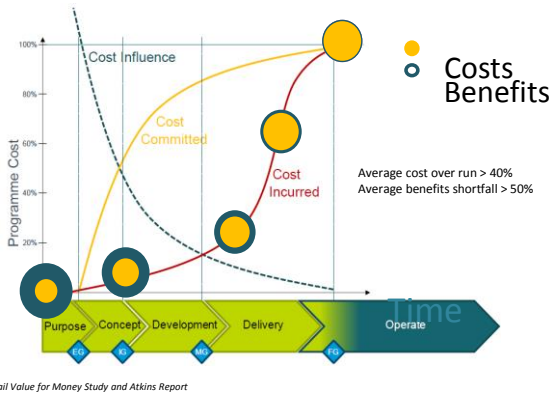
Both professional bodies profess to manage the delivery of business or customer needs, use controlled processes and cover the whole life cycle. One focuses on coordinated delivery of technical aspects, the other on coordinated delivery of the overall project (including technical aspects).

The Systems Engineers use processes to methodically breakdown the system to into subsystems, their associated functional requirements and any interface requirements between the subsystems and then monitor the rebuilding of the system. Programme Managers use processes to breakdown the programme to projects, plans, costs and risks, they then monitor the rebuilding the project. In fact you will note that INCOSE even considers cost and schedule, which are basic programme management building blocks.

As projects get technologically rich and complex, the Systems Engineering element plays a bigger role in the success of the programme. Hence it follows that for complex projects Programme Managers should pay closer attention to System Engineering processes and adopt or integrate them into the programme management plans. This paper will show how this may be done through examples where such methodology has been adopted.

3.4 Characteristics of Projects

Figure 1 below demonstrates how early systems engineering involvement in defining the system to deliver the benefits will provide a better probability that the benefits will be realised at the right time and cost [1].



Source: Rail Value for Money Study and Atkins Report

Figure 1: Cost - Benefit Characteristics of Projects

The actual cost incurred by a programme is shown by the red line. As expected, most of this is in the delivery phase. However, as shown by the yellow line most of the costs are committed by the end of the concept phase; approximately 80% of the costs are committed by 20% of the time duration.

The dotted line shows how the ability to influence costs diminishes rapidly part way through the design. The circles show what typically happens to the cost-benefit ratio through a programme lifecycle; to deliver value the project must protect both benefits and costs.

The first circle shows what the programme looks like when it is being promoted – a healthy 2 or 3 to 1 cost-benefit ratio. This phase is characterised by overconfidence in costs, over estimations in benefits and poor understanding of benefits. This represents the value that is expected from the programme when it is funded.

As we move through the concept phase the project gets more realistic about both costs and benefits, and by this stage the future maximum best performance is almost fixed, we have reached the sweet spot of costs committed and cost influence, from here onward it gets very difficult to change anything without reducing benefits or increasing costs.

During the design phase the project typically aims to a cost, so the only real way of reducing cost (because of over confidence at the start) is to de-scope (or value engineer), which typically means losing benefits, so now the benefit to cost ratio is looking very different from where it started, and it can only get worse.

Through the construction phase the project sees a difficult logistical and operational challenge, which we call the system migration. This is high risk and adds more cost.

So, by the end of the programme a large portion of the benefits have been eroded and the costs increased to an extent that the programme no longer represents value for money – the goal.

Unfortunately on such projects, benefit shortfalls 50% and cost overruns of 40% are common, and 100% cost overruns are not uncommon [3].

What is clear from this is that thorough and structured approaches to establishing the technical solution early with clear points to monitor progress against the desired benefits are required. In addition, what is required is a realistic schedule, and the associated cost and risks of the technical solution must be established with clear points to monitor progress.

Wouldn't it be nice to combine the monitoring points and characterise them by the parameters that measure the progress against benefits, cost, schedule and risk?

4. THE PROCESS

The methodology, Systems Integration Management, uses processes from the Systems and Programme Management realms to integrate the delivery. It enables progressive alignment of the different elements of the programme. It is based on the concept that programmes deliver outcomes, which are high-level, often qualitative, strategic goals; these outcomes are quantified in the form of benefits. In contrast, projects deliver outputs, which when integrated deliver the programme's outcomes. Thameslink, for example, is a programme which delivers outcomes (increased north/south passenger capacity through London, supporting economic growth in London and the southeast). Projects within the Thameslink programme include the new rolling stock, reconfigured stations, and longer platforms. These projects deliver outputs that are components of increased capacity, which when integrated deliver the programme's outcomes.

Figure II summarises the building blocks of Systems Integration Management. To achieve an output capability requires us to address the operational needs, the technology to deliver it and the programme and contract management demands to achieve success. The aim is to deliver an output capability (outcome) by focusing on common goals.

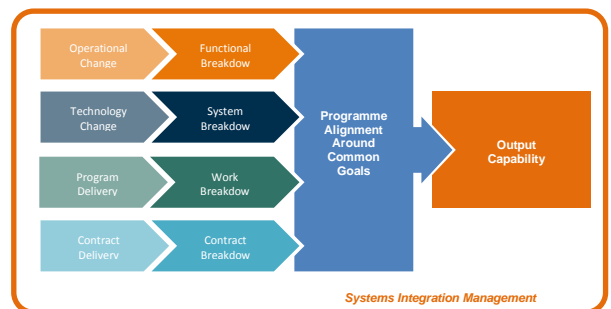


Figure II: System Integration Management Process

We look for high level outputs that characterise the programme and break these down into common goals that all partners and stakeholders can be integrated around. Progressively delivering these outputs or common goals leads to delivery of the benefits and overall capability.

The common goals are called Configuration Points (see Figure III); a point around which the whole programme is coordinated to achieve a common set of goals like:

- an operational change (e.g. timetable)
- a step change in performance (e.g. higher throughput)
- an introduction of a high risk new technology.

At each Configuration Point the programme should:

- integrate programme delivery
- integrate technology and operations
- reduce/eliminate major risk groups
- realise output performance
- capture benefits.

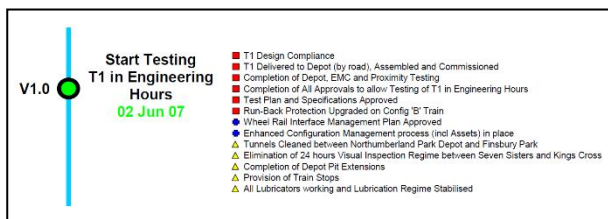


Figure III: Typical Configuration Point

To do this, integration must be performed considering four main areas:

Operational – This addresses the requirements of the ultimate customer and is normally outlined in a Concept of Operations or Operational Plan. These documents state how the Operator intends to operate the railway in normal and degraded modes, either implying or specifically identifying functions required to achieve these. The requirements will be broken down into a functional hierarchy, to be addressed by the system. Operational integration ensures that the functionality or capability delivered at different points in time is usable by the Operator, both in an interim stage and in the final configuration.

Technical – The clients’ scope, operational requirements and output capabilities, are broken down to functional and performance requirements which are then allocated to systems and subsystems. The requirements are captured in a database and each assigned characteristics based on the interim or final Configuration Point where they are realised. Achieving the output capability and functions will require monitoring the delivery in terms of compliance to technical

requirements, including safety, function, performance and operability. Integration in this sense means to integrate the system as a cohesive entity and to ensure that the delivery is coordinated as required at each of the Configuration Points.

Programme – The programme element will focus on delivering the scope by breaking down the project into defined pieces of work, with associated schedule and costs; identifying the risks and retiring them at the Configuration Points. Integration here is to ensure the systems and functions meet the operational demands at each Configuration Point, achieve these on scheduled dates and within the assigned budgets.

Contractual – The contract provides the framework and the context within which the participants delivery their obligations. The intention is to have common interim and final goals; the obligation for all parties to cooperate in this respect is essential in achieving overall success. The contract will also define the obligations for each party, the key milestones (which ideally would coincide with the Configuration Points), payments and penalties/incentives where these are deemed important...encouraging the right behaviours.

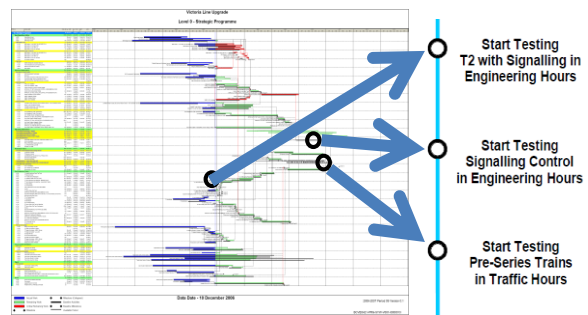


Figure IV: Simplified View of Schedule

The process must not only pull together all disciplines of the project, but it must unite the most important element, PEOPLE. To do this, the process must communicate the plans in a simple, easy to understand way. Figure IV illustrates a simplified view of what is a relatively complex project. When people understand what the plan is and the part they play in its success, the project is well on its way to success.

5. CASE STUDY 1 - VICTORIA LINE UPGRADE

The Victoria Line opened in 1967 as the world’s first Automatic Train Operation (ATO) railway. It is the only London Underground line that is completely underground. It is 21 km long, serves 16 stations from Brixton in the south to Walthamstow in the north, connecting the major hubs of Victoria Station, Euston Station and Kings

Cross and St. Pancras Stations with Central London. It is the most intensely used line on the network; in 2002 it carried 450,000 people a day with significant ridership growth predicted.

The full line upgrade project involved delivering a major increase in capacity whilst continuing to operate. Additional capacity was delivered through:

- new rolling stock
- new automatic signalling (ATO/ATP)
- new control centre
- traction power upgrade
- depot upgrade
- track upgrades
- enabling works for the above.

The combination of the above scope, allowed trains to run faster and closer together, with more passengers per train, and features to improve the flow of passengers on and off the train. The upgrade alone accounts for 10,000 passengers per hour.

5.2 The Complexity

There were a number of features of the delivery that made this complex; most significantly this was the world's first ATO-ATO migration. As the old trains needed the old signalling system to operate, the gradual introduction of new rolling stock driven by the new signalling meant that two ATO railways (old and new) had to inter-run on a very intense railway, with one still growing reliability. This coupled with the fact that at some point the railway control had to be migrated from the old control centre to the new meant that the control systems also needed to co-exist.

The next significant complexity was related to time and logistics. There were only two hours of effective work, on London's only line that is totally underground, with only one connection to the rest of the network. Access to the railway and the volume of work, meant very tight management of every minute of available time; competing priority given to the daily maintenance of a tired 40 year old railway.

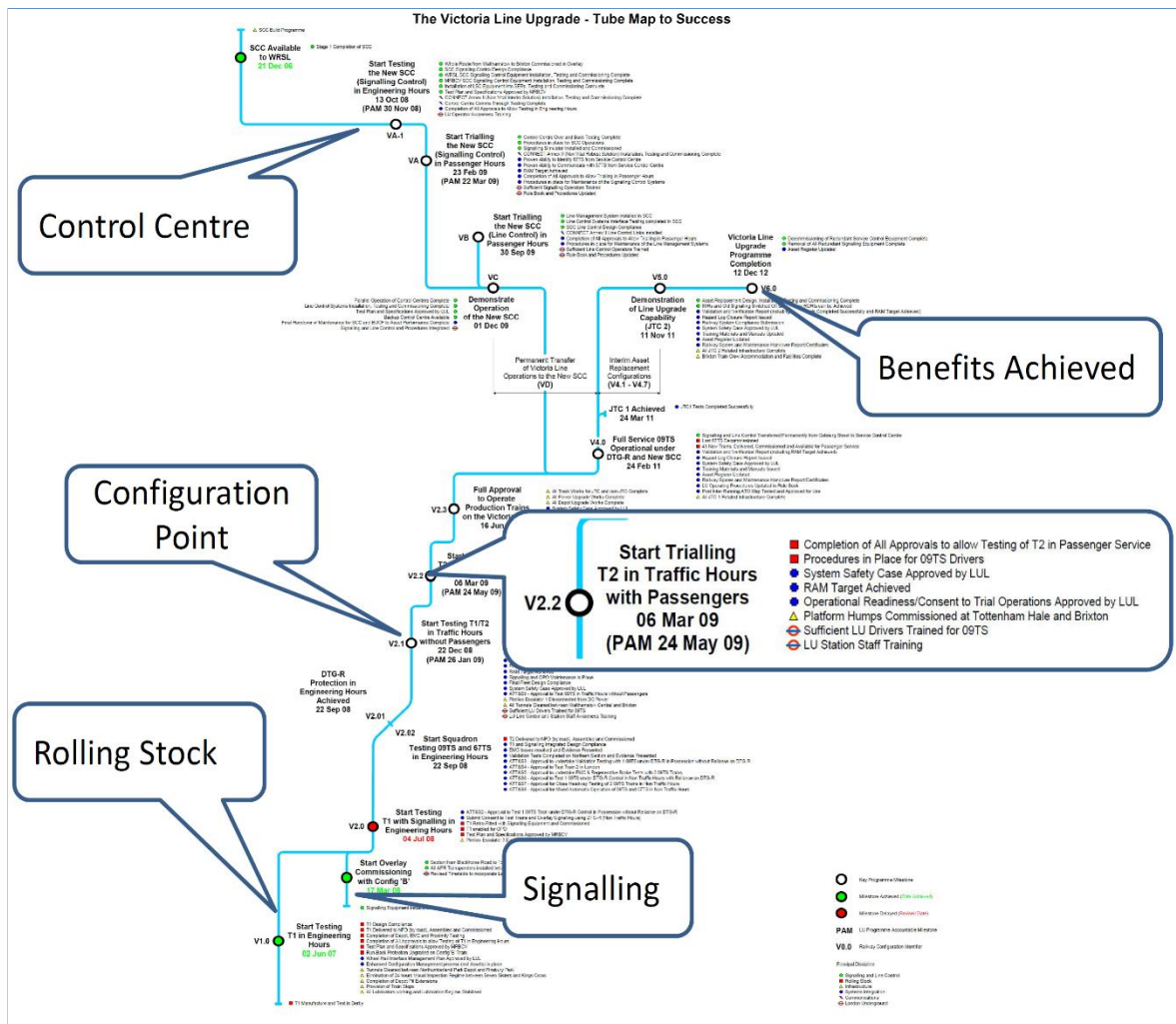


Figure V: Victoria Line Upgrade Tube Map to Success

5.3 Applying the Process

Figure V shows a graphical representation of the project schedule, outlining how the project was delivered in major steps, with rolling stock, signalling and control all integrating at key points in time. Each of the milestones along the way was called a Configuration Point (common goals), identified by their potential to disrupt the daily service, the operational change defined by its introduction, and significance to the project. Railway performance was modelled with the capability delivered at each stage linked to the benefits.

Each Configuration point was defined by the capability it delivered, requirements, physical architecture and performance. They were true integrating points, bringing together stakeholders and subprojects to ensure success. Configuration Point V2.2 in Figure V, was the start of daytime trials with a planned date, the list beside it defines the milestones that each sub-project and stakeholder needed to achieve for the Configuration Point. All planning and management of the project focussed around these points and determined the health of the project and its ability to deliver the desired benefits.

The 10-year long project delivered its output 17 months early with a capability exceeding the desired benefit. The Victoria Line currently operates a 33 train per hour service, carrying 650,000 passengers a day.

The innovative management technique, meticulous planning and control, strong teamwork and shared objectives made this project the pride of London Underground.

6. CASE STUDY 2 – THAMESLINK

Following on from the Victoria Line, a similar process has been adopted for the £6bn Thameslink Programme. Thameslink is a 50-station main-line running 225 km north to south through London from Bedford to Brighton, serving both London Gatwick Airport and London Luton Airport. It also includes a suburban loop that serves Sutton and Wimbledon. In 1998 it carried 28,000 passengers in the morning peak. The increased demand, as the only north-south railway running through London, drove the need for a major capacity upgrade. The upgrade is due to be completed in 2018 and the scope includes:

- new longer rolling stock
- new traffic control centre
- in-cab signalling with ATO
- power upgrades
- major track layout change, including 4-tracking, dive-under, tunnels and viaducts
- major stations redevelopments

- two depot upgrades
- consolidation of three operator franchises for a focussed service.

The existing railway is complicated with multiple operators and dated infrastructure; it struggles to push 17 trains per hour through the central London section. The upgrade, through longer and faster trains, improved layouts, major re-signalling, will deliver 24 trains per hour during the peak, with a 300% increase in trains through the central section throughout the day.

6.4 The Complexity

Complexity on Thameslink is everywhere; technically novel ATO functionality is being introduced with the first UK application of European Train Control System (ETCS) signalling on a mainline. This has significant implication on the infrastructure, rolling stock, operator and the telecoms network.

There are a large number of stakeholders, like Network Rail (the infrastructure owner and upgrader), the Department for Transport (purchasing the trains), three operators who must agree to enduring disruption and change with no promise of future involvement, London Underground and Crossrail Programme where major interchanges exist.

The rolling stock introduction requires coordination with the platform extension programme, and the stopping patterns in the corresponding timetable. Additionally, the outgoing fleet is part of a national cascade to franchises in the north of England, who have to be prepared for them.

The major construction sites in central London include the construction of two new stations at London Bridge and Blackfriars, extending Farringdon and building a viaduct near London Bridge. They present significant logistical and access limitations, with continued rail services.

The staged timetable changes over the delivery stage also impacts other main lines, including the new tunnelled connection to the East Coast Main Line.

The new Control Centre is part of a national traffic control scheme, covers a wider area and therefore requires significant coordination.

6.5 Applying the Process

The complexity of this project demands a single System Integration Authority to establish the joint deliver strategy; each stakeholder is represented by senior management. The operational changes, especially timetable changes, were deemed to be the best integrating points as all stakeholders had some involvement in their success. Therefore as Figure VI shows, all the relevant delivery sub-projects feed into the Operational Change line

where the common goals are delivered, the integrating Configuration Points.

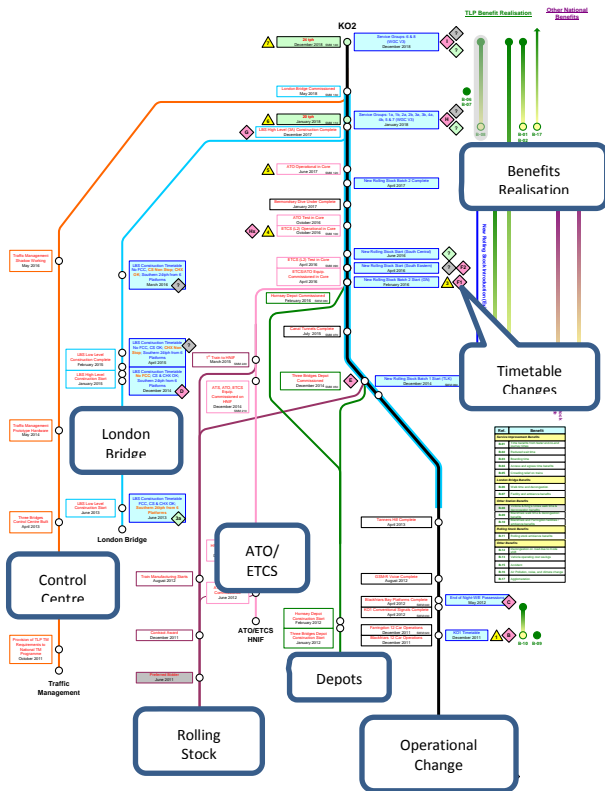


Figure VI: Thameslink Delivery Route Map

All engineering requirements are assigned to subprojects and the Configuration Point where they will be verified. These points are defined by a physical architecture, the realised benefit, operational capability, functionality, performance, safety related hazards and risks. Performance and the Configuration Points are monitored by the System Integration Authority, 'mini' Configuration Points are established for each of the subprojects.

Thameslink is currently on track to delivering the benefit in 2018, and has achieved key outputs with respect to the main infrastructure sub-projects.

7. INDUSTRY ACCEPTANCE

The Thameslink Programme's integrated approach to managing the delivery was singled out as industry best practice [1]. In particular the development of the Route Map and the setting up of the System Integration Authority were cited; modelling and communicating how the future railway will operate were credited with designing out non-value features and mitigating problems.

This has caused a number of major projects in the UK rail industry to adopt this or similar approaches, including Crossrail, Great Western Electrification and the Northern Hub projects. Similar processes are also being employed on Metro and Mainline projects beyond the UK, in Tel Aviv, Denmark and the Middle East.

8. CONCLUSION

As railway projects get more complex there is demand for a more structured and controlled technique for managing them. The processes employed must consider the multidisciplinary, multi-faceted nature of these projects. In the public eye, failure to deliver on promises is not an alternative.

The System Integration Management process responds to this need. It considers the complexity, breaks down the project in operational, technical, programme management and contractual terms, and integrates them around common goals. The delivery is then integrated around key delivery points, Configuration points, pulling in all involved disciplines.

The output is a graphically simple representation of the project, providing information about the key stages of delivery and the dependencies; communicating and connecting the current tasks to the context of the future goals.

The process integrates classical system engineering and programme management techniques, brings together all stakeholders and focuses on the common goals...which it communicates simply to all involved. It has contributed to successful delivery on the Victoria Line, is applied widely and has been recognised as best practice in the industry.

9. REFERENCES

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