The seven myths of railway systems engineering

Photo: F Schmid

STUDY Systems Engineering can help rail projects to be delivered more quickly and at a lower cost. But the industry does not fully appreciate what systems engineering is, and by debunking some commonly-held misapprehensions greater understanding of its benefits is possible.

Bruce Elliott, Clive Roberts, Felix Schmid and **Ian Shannon**
University of Birmingham

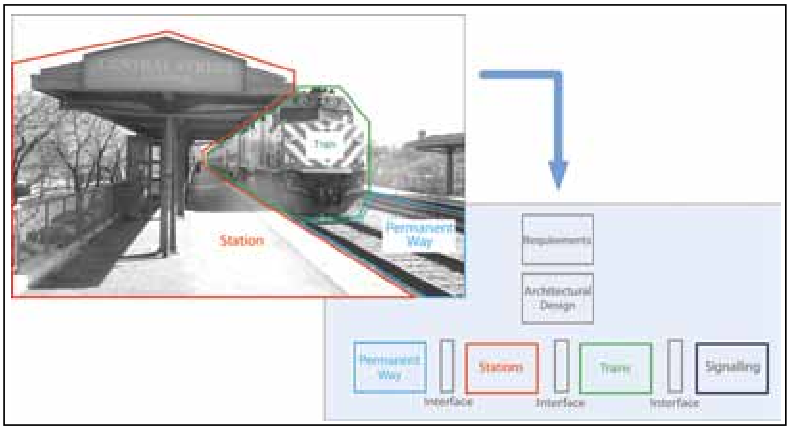
Although the defence sector has applied Systems Engineering (SE) since the 1940s, the rail industry has no comparable tradition. However, it is now being adopted increasingly by the rail sector, with SE departments established at London Underground, New York City Transit and Network Rail. A discussion on railway SE at the 2011 International Symposium of the International Council on Systems Engineering was attended by participants from some 10 countries.

Having practised, taught and researched SE in a railway context for more than 10 years, in this article we aim to put seven myths about SE to rest and, along the way, describe for the uninitiated what SE is and what benefits its application offers for rail projects.

Myth 1: SE is about connecting up computers

Some rail engineers use the word 'system' to refer to the parts of the railway with electronics and computers inside. For them, it is only natural to assume that 'systems engineering' means the business of getting the boxes with computers in them to work together to do what we want them to.

However, to a systems engineer, a system is any collection of hardware, software, people and procedures assembled for a purpose and so infrastructure, rolling stock and, indeed, whole railways are systems too.



Above: Students learning about railway SE at first hand on the Wien – Baden railway.

Right: Fig 1. Systems engineers see the railway as a system made up of interacting sub-systems.

Our first mythical definition of SE is not completely wrong, it is just too narrow. A better definition is 'the business of getting all the parts of a system to work together to do what we want them to do, effectively and in an efficient manner'.

As illustrated in Fig 1, systems engineers see the railway as a system made of interacting subsystems. But they are also concerned with things which are not visible on any photograph of the railway.

There are requirements, perhaps to transport certain numbers of passengers between certain points in comfort, reliably and safely. It is not possible to establish whether these requirements will be met by looking at any one subsystem alone — one must look at the whole railway.

There is, or at least there should be, a logic behind the way in which the railway is split into subsystems and the way in which they work together to deliver these requirements. A systems engineer might refer to this as 'architectural design'.

And there are also interfaces between the subsystems which must be carefully managed to deliver desired interactions such as train wheels rolling on the rails, while preventing undesired interactions such as trains fouling the platform edge. There is huge potential for problems to emerge if care is not taken over such interfaces. As Sir Peter Parker, a past Chairman of the British Railways Board, is reported to have remarked, railways have a habit of 'falling flat on their interfaces'.

Without accurate, clearly articulated requirements, a sound architectural design and carefully managed interfaces, a project is likely to disappoint. SE provides methods for avoiding such disappointment.

Photos: T Schmid

Rhätische Bahn maintaining operations against all odds in the streets of Chur.

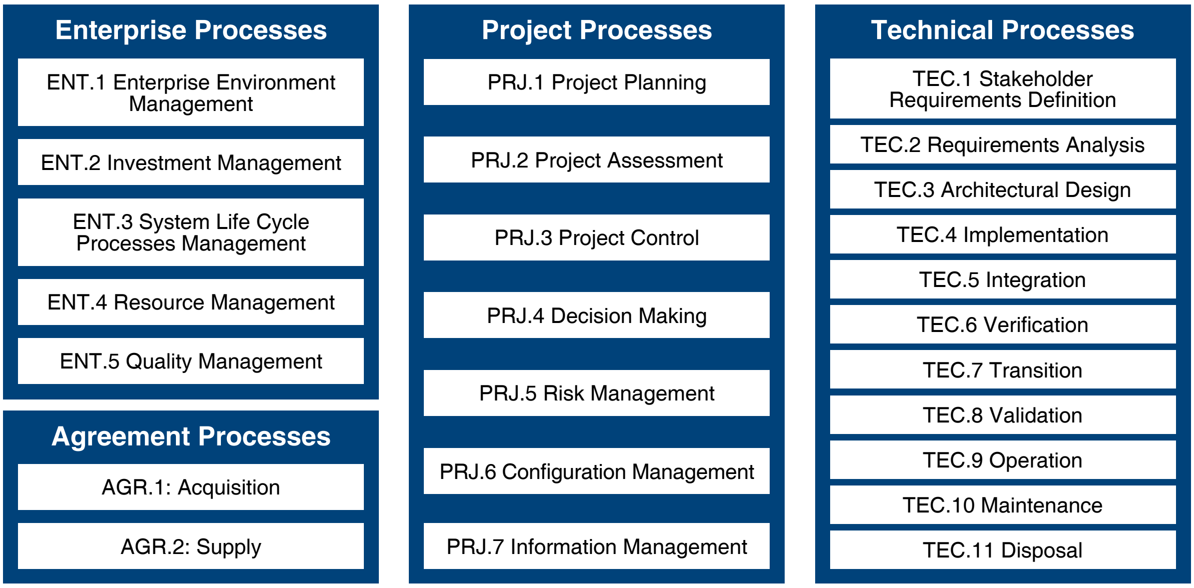


Fig 2. SE standard ISO/IEC 15288 structures its guidance under four main process headings.

Myth 2: SE is a well-defined discipline

Systems engineers like precise specifications and so it is an embarrassment to us to admit that we cannot agree on what precisely SE is. We do agree approximately. Few systems engineers would disagree fundamentally with this definition from INCOSE: 'systems engineering is 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, training and support, test, disposal and manufacturing.

'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's needs.'

Moreover, a comparison of a number of SE standards shows that all are agreed that it incorporates the following practices:

- establishing the scope of the system to be built and the requirements that it must meet;
- understanding how the system should be divided into subsystems and managing the interfaces between these subsystems;
- where practical and useful, performing systems modelling and analysis before the system has been built to check whether it will meet its requirements;
- validating that the system has met its requirements after it has been built;
- specifying the processes that will be used to design, build and check the system.

But there is still some disagreement at the margins. For example, some standards include aspects of ergonomics within SE while others regard ergonomics as an entirely separate discipline. Readers considering adopting SE within their organisation therefore need to be prepared to make choices at the margins about what to include and exclude under the title of 'systems engineering'.

Myth 3: SE is just common sense

SE certainly draws upon common sense. The list of activities outlined above draws upon the following common-sense principles:

- you should be clear about what you are trying to achieve before embarking upon a project;
- you should check whether you achieved what you were aiming for

Photo: C Watson

Systems engineering manages interactions across many interfaces for Denmark's railway.

Suspending Zürich's tram route 11 and the Forchbahn is simply not acceptable, even for a complete track renewal.

at the end of a project and, where practical, you should build confidence that you are proceeding in the right direction during the project;

- you should co-ordinate the activities of the parties involved in a project towards the agreed goals;
- you should plan out how you are going to carry out a project.

But SE offers more than just common sense. It provides proven methods for putting these principles into practice.

That, of course, is the nature of engineering. People can successfully build small wooden structures armed with an intuitive understanding of the properties of the materials and the forces acting on the structure, plus a bit of experience. But this does not make them civil engineers. Engineering implies the practical application of theoretical principles, and the design of larger and more complex structures requires engineering.

A move from common sense to SE sees informal written statements of requirements abandoned for structured databases, rigorously checked against defined criteria, and guesswork on reliability and performance replaced with justified estimates based upon computer models and simulations. Importantly, however, the introduction of SE also brings with it engineering judgement on when to use these tools and when less formal methods would be sufficient.

SE also provides a methodology, a logical framework within which its methods can be deployed. One widely-used SE standard, ISO/IEC 15288[2], structures its guidance under the process headings depicted in Fig 2. Adopting an SE methodology helps to ensure that best practice is followed, that resources are deployed effectively and that good work is not undermined by localised omissions and weaknesses.

Myth 4: SE is something completely new to rail
Myth 5: Rail projects have always done SE

These myths contradict each other, of course, but myths do not have to be consistent. Reality lies in between them. The problems that SE is designed to tackle are not unprecedented within the rail industry and the rail industry has developed its own ways of

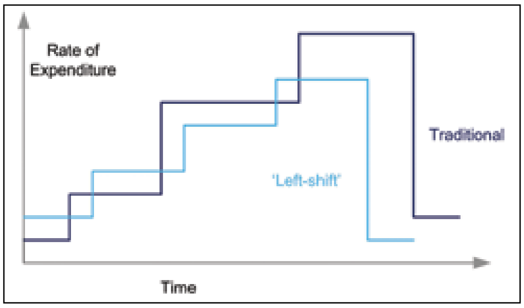


Fig 2. A comparison of the expenditure profile for a conventional project with that claimed for a project 'left-shifted' through greater use of SE.

dealing with them, which sometimes overlap with SE.

For example, SE standards call for multi-disciplinary reviews of emerging designs at major milestones. The SE tradition is to organise these as large review meetings held over several days. On the other hand, multi-disciplinary railway projects in the UK and USA tend to organise 'inter-disciplinary checks' during which a part of the design produced by one discipline is reviewed by the other disciplines. The railway tradition splits the multi-disciplinary review into a number of smaller checks but is clearly intended to achieve the same objective as the SE tradition.

This overlap leads some people to believe the opposite myth: that railway projects have always done SE. In reality, SE goes significantly beyond current railway practice. For example, railway projects have always specified the form and function of the systems that they were building, but SE also seeks to establish what the stakeholders really need. Often this is some improvement in overall system properties such as capacity, journey time or reliability. Stakeholders may have some preconceptions about the best way that such an improvement should be delivered but, if it can be shown that building a different system would deliver the improvement fully at a lower price, they may modify their views. SE tries to phrase requirements in a manner that opens up such opportunities.

Many SE practices are started early in the project lifecycle. The claim that investing in more SE earlier in a project will deliver more benefit later is often referred to as 'left shift'. Fig 3 compares the expenditure profile for a conventional project with that claimed for a project 'left-shifted' through greater use of SE.

One of the ways in which SE attempts to forestall problems is by using analysis and computer models to predict overall system properties, such as capacity, journey times or reliability, while the project is at the paper stage.

A 'left-shifted' project feels different from a conventional project. For a long time at the beginning, the only output is on paper. This is not always a comfortable process but experienced staff understand that the cost of resolving problems is generally much lower at the start of a project, when the team size is relatively small, than later on when the rate of expenditure is much higher.

So, importing SE ideas into a conventional railway project will build upon existing practice but extend it further. It is important to acknowledge this overlap and to bear it in mind when setting up an SE programme. It would be wise to hesitate before replacing a tried and tested method of doing things with a new, foreign alternative.

Myth 6: You can import conventional SE into rail unchanged
Myth 7: Railway SE is something apart

Another pair of opposed myths. Again, reality lies between them. By 'conventional' SE we mean the discipline as practised in those sectors where it was initially developed, particularly defence. We have learnt that there are at least three good reasons for adjusting the conventional approach for railway projects. One is a reluctance to disrupt existing ways of working unnecessarily as discussed above. The other two are as follows.

Firstly, railway projects are usually constrained by what has already been built, to an extent which would be unusual in the defence industry. To operate safely, electric rolling stock must be compatible with the track, bridges, tunnels, electrification system, signalling and platforms of the infrastructure on which it runs. Experienced railway engineers will be able to extend this list. As trains move across the network, they introduce long-distance connections between parts of the railway. Changing platform heights at one end of the country might require modifications to trains which would in turn require changes to platform heights at the other end of the country. So, unless they are building a new railway, railway engineers have to think about their work in terms of changing

British, Chinese, Indonesian, Korean and Turkish students learning about the tough human side of railway systems engineering.

the existing railway system.

This has implications for the way in which SE should be applied. SE handbooks advise the systems engineer to take the functional requirements and create an 'architectural design', that is to divide the system up into subsystems and allocate the requirements between these subsystems. But most of this has already been done for a railway system and the systems engineer's discretion in this area is limited to the specific aspects of the scheme. The conventional practices are still of value but they require adaptation.

Secondly, the railway must usually remain in service as the project is changing it. The project must be executed in stages which must be designed so that each can be commissioned within a short period of closure with railway operations resuming safely after each stage. We have yet to find a traditional SE sector in which the challenges of staging are comparable to those faced in the railway sector.

If one opens the INCOSE SE handbook, then one finds over 100 pages of guidance covering the project lifecycle, of which fewer than four cover the transition phase, the phase which encompasses this staging. In this area, the railway must significantly extend conventional SE practice — perhaps providing the basis of an expanded transition chapter in a future handbook.

But this does not mean that railway SE should be something apart, cut off from the reservoir of skills and experience accumulated by other industries. That would be a careless and unnecessary loss because the fundamental concerns faced by railway projects are more often than not the same as those faced by projects in traditional SE sectors.

It would also be an expensive mistake. Research based on 58 railway projects has identified average cost escalation of 44·7%[3], while another EU-funded study of large infrastructure projects[4] reports cost escalation of similar magnitude in several countries. According to the authors, 'the origin of reasons for cost overrun and time delay can more often be found in the planning rather than the construction phase. We noticed repeatedly that the technical, environmental and engineering or construction requirements and scope have been ill-defined at the initial stages of a project and publicly-stated cost estimates have been given, based on these uncertain principles.'

These remarks suggest that SE methods, with their focus on requirements and project definition, have the potential to mitigate cost escalation. Conventional SE offers effective techniques for tackling these concerns and railway projects are accumulating a successful track record of applying them with minor adaptation. When importing conventional SE practice developed in other sectors, we recommend adjusting them for railway projects where necessary, but only where strictly necessary.

The five realities of railway SE

Having disposed of seven myths of railway SE, we offer some realities to take their place. Because our seven myths included two pairs where reality lies in the middle, there are five realities:

1. SE may be thought of as 'the business of getting the parts of the railway to work together to do what we want them to'.
2. There are different views on precisely what SE is, which is distracting and inconvenient, but there is enough agreement to work with.
3. SE provides proven and well-grounded methods to put some common-sense ideas into practice and a framework within which to apply them.
4. SE overlaps with existing railway engineering practice but goes beyond it.
5. Railway projects should be prepared to adapt conventional SE approaches but only where there is good reason to deviate from established, proven methods.

As we have corrected the myths, we have observed that SE offers a reservoir of good practice that has been proven in other sectors to address the issues which can be so problematic for railway projects, including getting the requirements right, managing interfaces and avoiding disappointment with the performance of the finished project. We have noted that the railway sector is accumulating an increasing amount of experience in adapting this practice and applying it successfully. We conclude that such practice offers effective and applicable weapons in the struggle to deliver high-quality railway systems at reasonable cost.

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