'Picture this!', provoking stakeholder engagement through diagrammatic iteration

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Stakeholder engagement is often a significant challenge for the systems engineering practitioner, particularly in industries that are immature in their adoption of systems engineering techniques. Lack of understanding of systems approaches, and the value that they add, make it difficult to elicit input from clients, partners, and even other engineering disciplines. This paper advances techniques for improving engagement through the design of diagrams that cater to stakeholder needs, and that are developed in collaboration with them.

By providing a straightforward diagrammatic view of the system information, and making this view available to a wide audience, feedback on the structure and content of the information is typically more forthcoming. With this in place there is less reliance on right-first-time system information, and an iterative development process can be followed.

Examples of diagrammatic views are presented, along with explanations of their use in rail projects in both the UK and Australia. These show how engaging stakeholders through simple diagrams can be the start of a pathway into more advanced systems engineering techniques.

Stakeholder engagement

Stakeholder engagement is a mechanism used by most large organisations to reach understanding and agreement around complex or concerning issues relating to their business. It forms a key part of corporate social responsibility, where stakeholder engagement is often used as a synonym for public engagement; however, depending on the area of an organization's business, the set of stakeholders may be significantly wider than just the general public. For example, in major infrastructure programmes the public will typically be engaged as an end user, alongside operators, maintainers, manufacturers, supply chain organisations, governmental bodies, regulators, design and build contractors, facilities providers, shareholders, and many more.

The responsibility for engaging with stakeholders is usually split across the organisation depending on the task at hand, and could fall to one of several internal departments. For an engineering project it may be the task of either project management or systems engineering. From the perspective of systems engineering, it is often beneficial to detail which stakeholders relate to the specific systems of interest. In the systems view, stakeholders can exist within the organisation or delivery programme, such as: engineering disciplines, related projects, safety representatives, and management.

Engineering stakeholder management is a large field that is well covered in the general project management literature, for example by the Project Management Body of Knowledge (PMBoK).[4] It typically involves activities such as stakeholder identification, analysis, mapping, planning, and management. One aspect that typically comes under the remit of the systems engineer on a project is the definition of stakeholder needs.

[4] Project Management Institute. Project management body of knowledge (PMBOK). 2017

The Systems Engineering Body of Knowledge (SEBoK) recommends a number of approaches for collecting stakeholder needs and requirements, a number of which are diagrammatic, e.g. use case, functional flow or activity diagrams.[5] SEBoK also lists the following as major pitfalls encountered in dealing with stakeholders: the operator role not being considered; exchanges or physical connections with external objects being forgotten, and stakeholders being forgotten.

[5] SEBoK contributors. Systems engineering body of knowledge (SEBoK) – stakeholder needs and requirements. 2017

Although the focus within the systems engineering literature is typically on needs and requirements, there is a wealth of other information that should be gathered from stakeholders, particularly in large scale integration programmes where it can be difficult to agree a common understanding of programme aspects such as scheduling, design input, and interface ownership allocation. In this work we are interested in this larger problem of engaging engineering stakeholders, to provide and agree on a specific set of technical or project information.

Outside of systems engineering a similar problem is addressed in various fields involved in large scale societal change, such as sustainable farming methods or climate change mitigation, where stakeholder engagement plays a vital role.[6] Research in this area has proposed a number of models around the concept of a ladder of participation.[7] These typically range from non-participation at the bottom of the scale, through information provision and consultation, up to partnership and, ultimately, stakeholder control at the top. The general message being that increasing participation, through changes in project engagement approach, will lead to improved outcomes overall. This type of model has been criticised however, for failing to capture the dynamic nature of user involvement and users' individual agency in determining their own level of involvement.[8] Applying the ladder of participation concept from an engineering perspective these criticisms seem valid, alongside a general concern that most stakeholders would simply not be qualified to take full control (the top of the ladder) in the type of projects we are interested in. Those points notwithstanding, the approach proposed in this paper is aimed at moving stakeholders up the ladder of participation.

[6] Debra Sequeira and Michael Warner. Stakeholder engagement: a good practice handbook for companies doing business in emerging markets. *International Finance Corporation*, 2007

[7] Sherry R Arnstein. A ladder of citizen participation. *Journal of the American Institute of planners*, 35(4): 216–224, 1969 ; Roger Hart. Ladder of young people's participation. *R. Hart Children's Participation from Tokenism to Citizenship*, 1992 ; and Jules N Pretty. Participatory learning for sustainable agriculture. *World development*, 23(8): 1247–1263, 1995

[8] Jonathan Quetzal Tritter and Alison McCallum. The snakes and ladders of user involvement: moving beyond Arnstein. *Health policy*, 76(2):156–168, 2006

The need for a cycle of stakeholder consultation is well recognised, with five steps for iterative consultation being proposed as: plan ahead; consult using basic principles of good practice; incorporate feedback; document the process and results of consultation; and report back.[9] This provides a sound general concept, but does not detail specifics in achieving the steps; here we provide those

[9] Sequeira and Warner, 2007

details in the specific context of systems engineering.

In developing any effective stakeholder engagement approach negative psychological and social phenomenon such as the bandwagon effect (increased acceptance of ideas based on their adoption by a number of others), groupthink (poor decision making due to a desire for conformity) and communal reinforcement (increased preference for ideas due to their repeated assertion within a community) should be taken into account. In contrast there are also a number of positive effects that should be maximised such as the wisdom of crowds (the tendency for estimation from a group to be better than from their individual members) and the benefits gained from collaboration and peer review.

A number of general purpose approaches to crowdsourcing information have been implemented to attempt to address these issues and magnify the positives. These include techniques such as prediction markets (aggregation of information through the placing of bets) and the Delphi method (iterative facilitated forecasting by a panel of experts to reach consensus predictions). Whilst these may be too complex and resource intensive for most stakeholder engagement issues, some of their key strengths are noted for application to our process, specifically:

- Gathering input from a large number of contributors;
- Polling of participants individually;
- Repeated iterations to drive towards consensus;
- Review of results and reasoning in between iterations;
- Weighting of responses based on the responders' confidence and credibility.

A number of these are built-in to the proposed process, others should be considered by the practitioner during its implementation.

Diagrams in systems engineering

A case can be made that the use of diagrams, or more generally, data visualisations, is an essential systems engineering skill.[10] The importance of ensuring communication and collaboration in order to manage interfaces — between both different disciplines and disparate stakeholders — requires an approach that is effective, formal and precise. Alongside unstructured free-form text, structured diagrammatic approaches are frequently used to fulfill this need. In general, these may take the form of: work breakdown structures and Gantt charts in project planning; 2D and 3D design images in computer-aided design (CAD); flowcharts and systems models for process control; bar, scatter and pie charts in reporting; dashboards and control panels for human-factors work. Within systems engineering there are many further system views that can be

[10] John Welford. Data visualisation for systems engineers. In *INCOSE UK Annual Systems Engineering Conference*, 2016

represented graphically, including: requirements traceability; functional/product/system breakdown structures; interface matrices; cause and effect diagrams; and sequence diagrams.

Certain techniques and disciplines take this a stage further, centering the whole engineering process around modelling and visual methods. Model-based Systems Engineering (MBSE) is an increasingly widely accepted approach to practicing systems engineering; the INCOSE Systems Engineering Vision 2025 positioning paper states: 'Model-based Systems Engineering will become the "norm" for systems engineering execution, with specific focus placed on integrated modelling environments.'.[11] MBSE is centred around using an information repository, or model, as the single source of truth on a project. The information contained in the model is typically both presented and edited in diagrammatic form.

[11] INCOSE. World in motion: Systems engineering vision 2025. *International Council on Systems Engineering, San Diego, CA, USA*, 2014

Other disciplines and domains are also pushing to operate in a more digital-centric manner.[12] Building Information Modelling (BIM) is a process finding increasing use in infrastructure programmes that uses three (or higher) dimensional federated digital physical structure models, sourced from multiple disciplines or parties, as the central design resource. Two dimensional diagrams may then be rendered from the main model for review and production. This bears a close resemblance to the MBSE approach, and the similarities between the two is an area of active investigation.[13]

[12] WSP | Parsons Brinckerhoff. Digital life, digital legacy, 2014

[13] James Towers. Update on MBSE & BIM work-stream, September 2017

In industries such as aerospace and defence, where systems engineering techniques were originally developed and proven, stakeholders have generally been on the development journey alongside the systems engineers, and therefore the highly-evolved products of modern systems engineering tend to be well accepted. Relatively complex notations such as the Systems Modelling Language (SysML) are recognised, understood, and provide an effective means of communication. It has been noted that these types of highly-evolved notation may be less well accepted by stakeholders in other domains, such as rail.[14] In these cases it is contended that simplified or more familiar diagram types may generate improved stakeholder engagement.

[14] Welford, 2016

In this paper we propose a process for developing diagrams in active collaboration with stakeholders, and present case studies around two diagram types that have been shown to work well in the rail industry. These demonstrate increased stakeholder acceptance of the diagrams and their information, due to their involvement in its evolution.

The specific details of implementation are not prescribed by the process, meaning it may be used for the production of isolated diagrams, or as part of a larger more integrated information management approach. It is recommended that an integrated approach be pursued where possible, allowing the production of multiple different diagrams from the same set of background data. This also allows the development of interactive diagrams, which can display additional or alternative information based on user selections.

Diagram development process

An overview of the process is shown in Figure 1 with each step being outlined in more detail below.

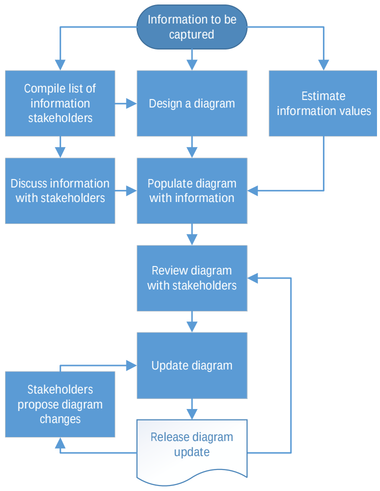

Figure 1: Diagram development process

Prerequisites and assumptions

The process outlined in this paper is concerned only with the engagement of stakeholders on a particular set of information. This may be related to needs and requirements, or it may be aspects of design, system operation, interface management, programme scheduling, funding, task allocation, or any number of other engineering issues. The term stakeholders is also used in the broadest sense, to include not only the end-users of the system of interest, but also all those involved in its procurement, design, delivery, commissioning, operation, maintenance, governance, and disposal.

We assume that this process is surrounded by an effectively implemented stakeholder management plan; detail on achieving this is beyond the scope of this paper, but is extensively covered by guides such as PMBoK.[15] At process commencement the relevant stakeholders should already be mapped and analysed, such that their involvement, understanding and influence are understood. Throughout the process it is possible that new stakeholders may be identified; these should be noted and the management plan updated accordingly.

[15] Project Management Institute, 2017

We also assume that the stakeholder review and discussion process happens in a distributed manner, rather than with all stakeholders around one table. Often the sheer number of stakeholders will make this difficult, and they are regularly preoccupied with other work that makes your information requests a relatively low priority for them. Where it is possible to arrange group stakeholder meetings then the process can progress much more rapidly, however there are also downsides to this approach – such as direct conflicts between stakeholders, and the issues around groupthink, bandwagon effect, and communal reinforcement noted above. The best approach will need to be determined on a case-by-case basis, however the absence of even a single stakeholder from a meeting room requires that a distributed process be followed. Where group meetings are used then a very similar process would still apply, but iteration on the steps of diagram update and review may happen very rapidly within a single meeting.

Where information is already documented then its original source data should be investigated. Our process does not provide for input from non-stakeholder sources, as this type of data is either incontestable fact – in which case it is not open to stakeholder discussion and the process is not required, or it is sourced from a stakeholder – in which case they need to be included in the process.

Process start – Information to be captured

The process commences when a set of information is identified as required by the project, which needs to be sourced from, or approved by, a set of stakeholders. This information should have a clear, concise and unambiguous definition. At this stage it may be helpful to structure a spreadsheet or database to record the information when it is captured. This should prompt consideration of the relevant set of attributes that will accompany each data item. As mentioned previously, consideration should also be given to integrating information from multiple diagrams into a single dataset.

Compile list of information stakeholders

As a full set of stakeholders should already be known for the project, this may be reduced to a smaller set to whom the information is expected to be relevant. Where the stakeholder is a whole organisation or team then an individual should be nominated as a point of contact. This will form the distribution list for later diagram release, and a review panel for discussion about the diagram and information. It will also shape the design of the diagram, which may need to be at a high or low level of detail depending on the depth of stakeholder knowledge.

Ownership of information should be considered at this stage, ideally as part of a configuration item identification process. This is necessary to ensure accountability, enabling the authorisation of baselines and the sign-off of diagram releases.

Discuss information with stakeholders

Once a set of stakeholders for the information is identified then initial discussions with them can begin to appraise their views on what the data should be. It is suggested that this be done without reference to any new diagrams, and be based purely on stakeholder descriptions and any information sources that they are able to provide. The introduction of new diagrams containing incorrect information at this stage is likely to be disengaging and should therefore be avoided.

Design a diagram

Based on understanding the information required, and the set of stakeholders with an interest in it, a suitable diagram may be considered to display it. The term diagram is used in the loosest sense here as, for small information sets, a simple table of data may be sufficient. A wide range of standard diagram types are available in common software tools that may be able to assist with this, and there is considerable literature on diagramatic best practice which should be followed.[16] For certain information it may be beneficial to design bespoke diagrams to capture data across multiple dimen-

[16] Stephen Few. *Show me the numbers: Designing tables and graphs to enlighten*. Analytics Press, 2012

sions, or to ensure that the presentation method is familiar and acceptable to the key stakeholders.

It is important to ensure that the diagram produced is both useful and attractive. The aim is to have something suitable for displaying in print format on a wall, or that can be laid out on a table for discussion at a meeting. Producing a useful and attractive output will substantially increase the engagement of stakeholders and provoke significantly more feedback on its correctness. During design and development of the diagram it is strongly recommended that the visual aspects be 'data-driven', such that the actual data may be stored separately. This will considerably reduce the workload involved in updating the diagram, promoting faster updates and increased iterations. This is especially relevant where the diagram is tailored to specific stakeholder groups, and therefore the same data may be used to drive multiple diagrams.

Associated with this an effective configuration control mechanism should be set up for both the diagram itself and its background data; the data should be recognised as a configuration item, with the diagram representing a stable baseline of the item at release. This will ensure clarity during discussions with stakeholders who will undoubtedly end up working from an outdated version at some stage.

Estimate information values

Alongside diagram design and stakeholder discussions it is useful to make some estimation of the information that we expect to gather, based on experience and sound engineering judgement. For many information sets there will be data that stakeholders are simply unable to supply or even suggest; for these it is useful to have some starting point to guide discussions. Significant deviations between estimates and stakeholder supplied data can also be a useful indication that discussions are happening at crossed-purposes and should prompt a more detailed conversation about what the data actually means.

At this stage some thought should also be given to the best way to indicate on the diagram that data has some uncertainty about it. Dashed lines, bounded regions or fuzzy edges can all be reasonable ways to convey this information. It should be clear to a viewer that certain data has been stakeholder supplied, whereas other data is the product of estimation. Ideally this will prompt the supply of more accurate data as the process continues.

Populate diagram with information

Once initial data has been gathered and/or estimated, and the structure of the diagram and data-set established, it should be straightforward to populate the diagram to produce an initial version. This will almost certainly be wrong in some way, but hopefully it is sufficient to demonstrate what is required at the end of the process. The remainder of the process is simply the correction of errors in this first version.

Review diagram with stakeholders

It is recommended that the diagram not be directly released to stakeholders at this point, particularly if it contains a large amount of data not sourced from them, or it is in a format that they are not used to; this can be disengaging and produce a level of distrust in the diagram that may be hard to regain. Instead consider reviewing the diagram with each stakeholder in turn, discussing the source of information and why the diagram design has proceeded in this manner. This exercise can be time-consuming, but it will build an initial understanding and confidence in the product that will pay dividends later in the process.

During the review period it is worth being cognizant of the stakeholder's appetite for the review meetings and their level of energy. Where multiple reviews are conducted, there is a risk of stakeholder exhaustion. This needs to be gauged and managed in order to keep the stakeholders engaged with the process.

Update diagram

These initial reviews are likely to source a large amount of feedback on what is wrong or missing from the diagram. This data should be collected and passed through the version control system ensuring that the source of each data item is clearly noted. The diagram may then be updated to produce a second version which is ready for release to stakeholders.

Depending on the complexity and contentiousness of the information being determined, many iterations and releases of the diagram may be necessary – it is highly unlikely that it will be correct after the second release. Stakeholders will have different views on what the correct set of data is, and these will take some discussion to resolve. Missed data items will also come to light as things progress.

Release diagram update

Release to stakeholders should be well coordinated and use a fixed distribution list. The aim is to ensure that everyone is working from the same up-to-date set of information and that previous versions, which may have been posted to notice boards or distributed to third parties, are also updated. Having the whole process implemented within an overall configuration management system will help substantially at this stage.

During release the iterative nature of diagram development should be emphasised to stakeholders, to encourage the provision of feedback and to prepare them for the possibility of changes to the data in the future.

Stakeholders propose diagram changes

Once stakeholders have had time to review a new release of the diagram then specific discussions may be set up to discuss changes or additions to the data set. Once the process is working well and the diagram has been accepted by stakeholders then proposed changes to the diagram may start to come in unsolicited – when stakeholders begin referencing the diagram without being prompted you will know that you have created something of value and that the process has become sustainable.

Outcomes

This process follows the proven practices outlined in SEBoK: involve stakeholders, capture rationale, use modelling techniques, and use tools.[17] It allows for stakeholders to be taken on the journey of diagram development with the systems engineering team, and provides the following benefits:

[17] SEBoK contributors, 2017

- Better project outcomes due to increased knowledge input;
- More educated stakeholders in the process of system engineering;
- Increased networking with the stakeholder community;
- Higher likelihood of information/diagram acceptance by stakeholders due to accountability for its development;
- Early identification of project delivery issues due to a regular review cycle;
- More complete modelling of the system of interest.

Case studies

WSP has a proven track record in delivering systems engineering consultancy to infrastructure clients internationally on numerous world class projects. In this section case studies are presented to show how the implementation of the process described above provided effective engagement with stakeholders on two large scale rail programmes. The systems engineering role in both cases was focussed on systems integration across multiple projects. WSP has a tried and tested framework for this type of integration, of which the process outline here forms one component.[18]

[18] Malcolm Thomas, Paul Carter, and Alan Knott. SE for different industries: one size fits all? In *INCOSE UK Annual Systems Engineering Conference*, 2013 ; and Steven Turner and John Welford. System integration in a fragmented rail industry, September 2016

Throughout the case studies reference is made in the sidenotes to the applicable process steps that were followed.

Physical Architecture diagrams in London Underground

The London Underground Deep Tube Upgrade Programme offered up a complex system of interest whose lifecycle spans 40 years

Since 2014, WSP has been the lead systems integrator for the Deep Tube Upgrade Programme in London. The programme is a multiple line upgrade, introducing new rolling stock, a new signalling system, altered track configuration, and a new operational concept.

(from feasibility to design, implementation, and through to eventual decommission of rolling stock).

Initial modelling of the systems had been carried out, before the arrival of WSP. It was done using a specific MBSE tool which, whilst not necessarily wrong, was difficult to validate due to lack of rail stakeholder engagement with the SysML diagrams used. The team met with the stakeholders to understand why the SysML diagrams weren't working and what they needed. Feedback was that the SysML appeared to be developed 'just for the sake of it', and some value needed to be demonstrated in the development. In order to specify and understand the components of the system and their interfaces, based on input from the project Engineering Design Group and Project Sponsors, a new physical architecture view of the model was produced.

Information to be captured

Information stakeholders

Design a diagram

Each element on the physical architecture represented an element in the original model, but was accompanied by pictorial representations of the rail assets to produce a more engaging diagram that was understandable to the stakeholders. This type of system view is particularly beneficial in the rail domain due to projects typically representing an incremental upgrade of existing infrastructure, therefore gaining a clear understanding of the current system which is essential before considering any additions or changes occurring within the project.[19]

[19] Welford, 2016

The development of the physical architecture started on a small scale, focussed on the train and its current components and interfaces, as shown in Figure 2. The Train was chosen as the first focus area due to the project being very *train-centric*. The first draft of the train physical architecture was populated based on the development team's domain knowledge to represent a *generic* rolling stock system. Although the diagram was not fully correct at this stage, it was suitable for the first review with stakeholders. The elements were mostly placeholders to prompt discussion with the stakeholders and provoke familiarity with the level of detail contained in the diagram.

Populate diagram

Estimate information values

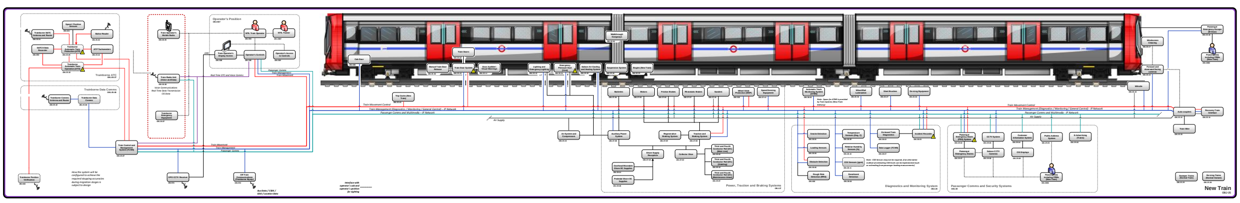

Figure 2: Train physical architecture

It was noted that the stakeholders found the diagram easier to relate to than the spreadsheets used to store the raw information. The diagram also made an impact within the London Underground office due to its very visual nature.

Following reviews of the initial drafts with specific rolling stock and train control systems engineers, followed by diagram updates,

Review diagram

Update diagram

Release diagram update

the physical architecture of the current train was released to wider stakeholders for endorsement. Encouragingly, even at this early stage, stakeholders began to identify discrepancies and knowledge gaps.

From developing the train section it became evident that there needed to be depot and maintenance facilities to maintain a new type of rolling stock. So the diagram was expanded to cover the train maintenance and stabling areas, as shown in Figure 3.

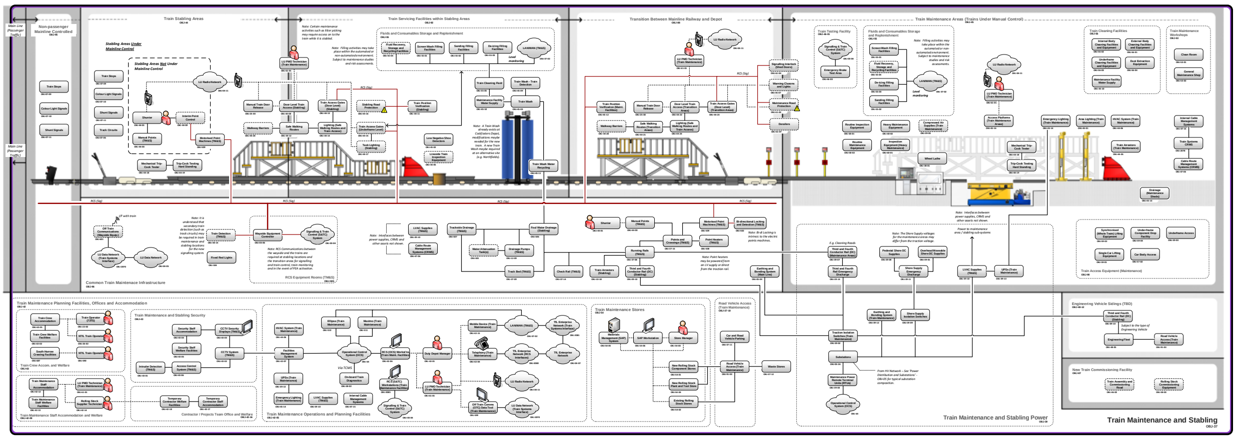

Figure 3: Train maintenance and stabling physical architecture

Stakeholders propose changes

With each iteration of the diagram, it became more accurate and was used more extensively by the stakeholders in meetings and workshops. Eventually a diagram of the whole system of interest was developed, having been validated by the stakeholders throughout its development; a version of this is shown in Figure 4.

Whilst updating the diagram a Product Breakdown Structure (PBS) database was built to record technical data relating to each element, supported by an interface register. The PBS formed the *single source of truth* for the project and contained over 550 unique elements, split into 21 high level groupings and broken down in up to six layers to get to the lowest-level elements. Each element was eventually included on the physical architecture diagram. This provided an information repository where:

- All the identified rail assets/elements existed in one database;
- All the technical and project information about an element was recorded;
- Each element was assigned to a specific group of stakeholders for ownership;
- Each element had its interfaces recorded and linked to an interface register;
- Each element was linked to functional and non-functional requirements;
- Elements could be linked to assumptions and risks.

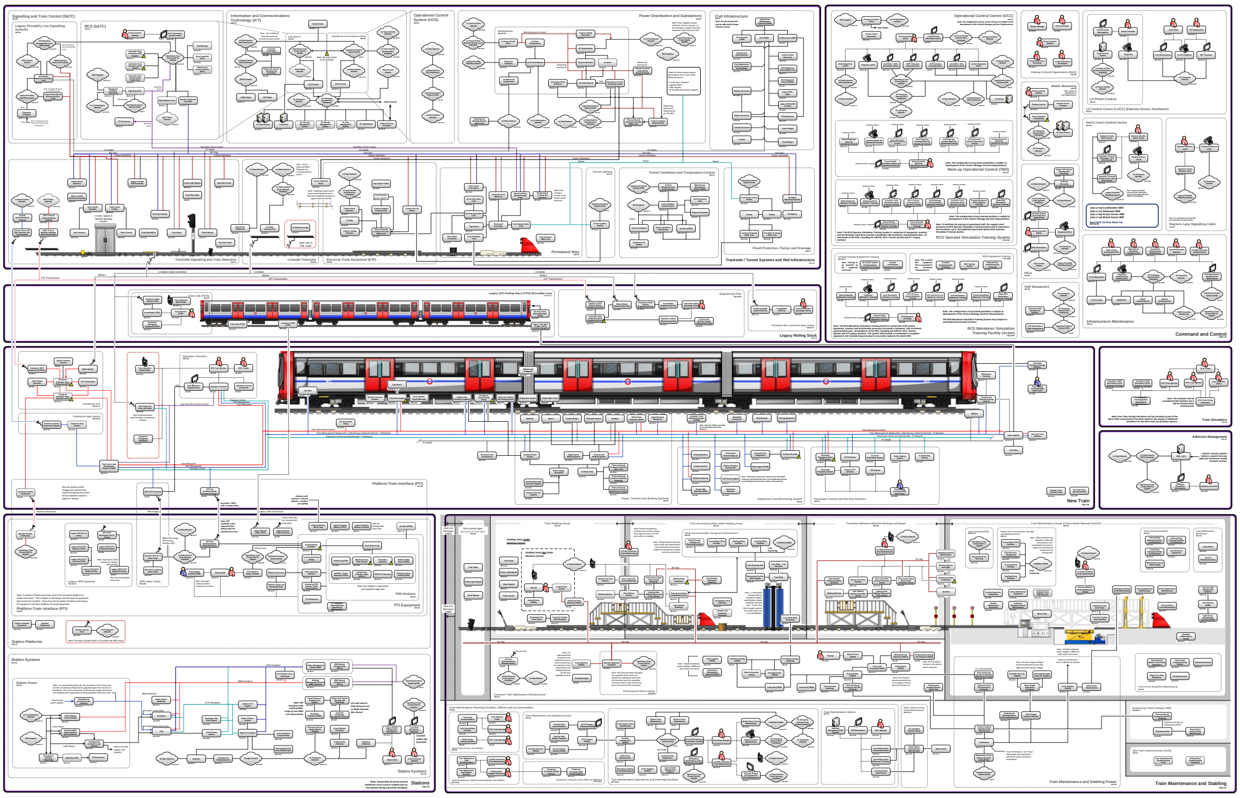

Figure 4: Whole system physical architecture

All of this was built on a high level of stakeholder engagement and stakeholder adoption of system engineering practices. Considerable effort was expended in developing the first iterations of the physical architecture, however there were clear benefits in taking the stakeholders on the development journey and in the resulting approved PBS database. The physical architecture was the tool that enabled the team to more accurately and comprehensively create the database and encouraged the stakeholders to take ownership of the design. Once the database was complete it enabled the team to derive multiple views of the physical architecture and analyse the effects of change. The views become very powerful as they allowed the stakeholder to view:

Update diagram

- Ownership of elements, showing the split between rolling stock, signalling, and infrastructure project scopes;
- Status of elements during programme migration (*Modified*, *Unmodified*, *Removed*, or *New*);
- *Configuration State* views, depicting what the system of interest looked like at each of the seven phases of the project;
- *Grey areas* showing elements that were poorly understood or that had decisions pending on them.

Elements that interface with a stakeholder's sub-system, e.g. signalling interfaces that are within the scope of the rolling stock project. Each view of the physical architecture was configuration controlled in line with the baselining of the PBS which contained the background data. The most adopted views of the physical architecture were the project scope view and configuration state views. Printed architectures on A0 size paper were often posted on walls in stakeholder meeting rooms and project areas for project teams to use as a reference and *source of truth*. The widespread acceptance of the physical architectures resulted in ad-hoc highlighting of opportunities to design in efficiencies and design out risks by project teams during the feasibility stage.

Release diagram update

Stakeholders propose changes

Through following a diagram iteration process on the Deep Tube Upgrade Programme the systems engineering team went from having stakeholders that continually questioned the need for systems engineering on the project, to them not only understanding the need for systems engineering, but also happily adopting the outputs as their *source of truth*.

This was attributed to being able to clearly see, on one page, the physical interactions that elements have with one another, and how they evolve over the life of the project. It enabled projects to understand what products were within their scope, and what interfaces they were responsible for delivering. It also highlighted the grey areas where the system was not well understood, or a decision needed to be made in order to assign ownership of a product.

Migration Plan diagrams in Public Transport Victoria

Public Transport Victoria (PTV) is the statutory authority that manages Victoria's public transport network. As the network assurer, PTV are responsible for the connectivity, reliability, safety, security and environmental impact of the public transport network, along with ensuring new projects are compatible with existing infrastructure and operations. Since 2015 WSP has supported the development and management of integrated project delivery within PTV; ensuring a holistic network level approach and providing an overall system integration and assurance process.

In support of integrated project delivery within PTV a full suite of diagrams were developed, including physical architectures, geographic architectures, network schematics, and interaction diagrams. A key step that initially helped to engage PTV stakeholders, providing *buy in* to whole systems engineering process, was the use of migration plan diagrams.

The initial migration plan was developed for PTV's Integrated Major Project Branch. The purpose of the migration plan was to help PTV and its stakeholders, including five major projects and several government agencies, understand and clarify the scope of the various projects works being delivered along a new rail corridor (joining two existing rail corridors). The required information regarding the scope of works included key delivery dates, infrastructure and operational changes to the corridor, and known interfaces and dependencies between projects.

Information stakeholders

Information to be captured

The migration plan is diagram which shows critical interdependencies of programme elements, aligned to key programme configuration points and important milestones, on a single page; an example of which can be seen in Figure 5. This simple visualisation of deliverables relevant to the stakeholders can show information at any level in a programme hierarchy, quickly identify interdependencies with other deliverables, highlight the deliverables necessary to achieve a milestone or configuration state, and be adjusted to

Design a diagram

suit the user needs. This type of view is invaluable in large rail programmes where the railway must go through multiple phases of development, whilst remaining operational throughout.[20]

[20] Welford, 2016

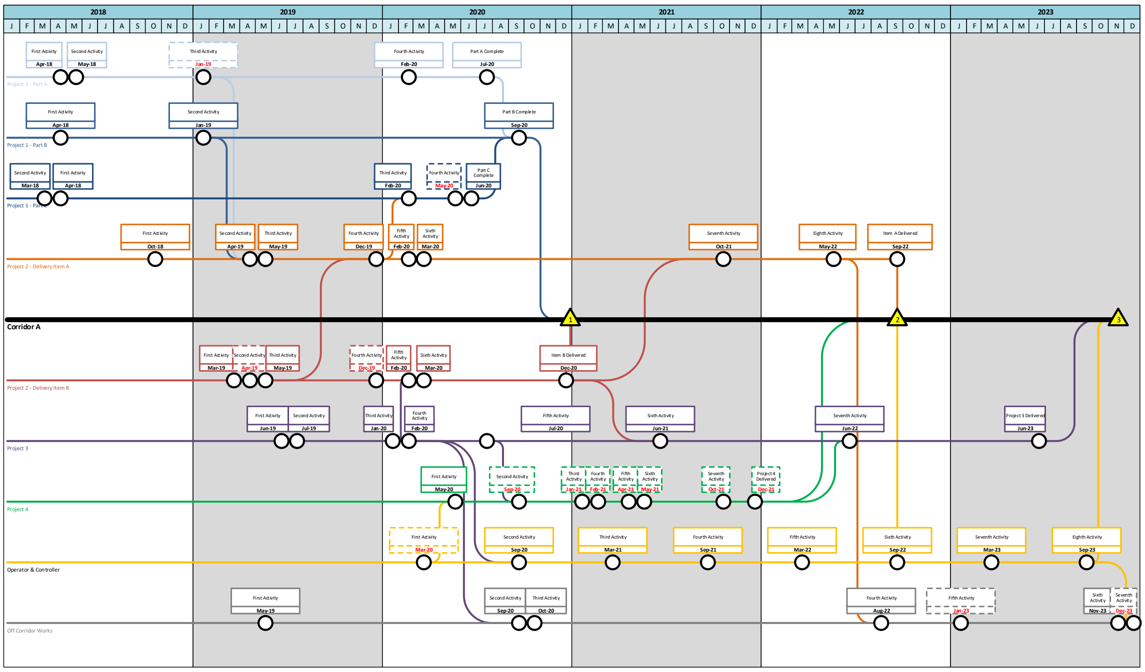

Figure 5: Example migration plan

Estimate information values

Discuss with stakeholders

Populate diagram

The first iteration of the migration plan was developed based on a high-level understanding of the corridor projects and deliverables. Various project assurance managers were consulted, and the data input was supported by current projects and programmes. The result was a migration plan based on a large set of estimations and assumptions, it used dashed lines in the diagram to show the information that was unclear to PTV as the network assurance authority, therefore highlighting the need to directly engage with additional project stakeholders.

Review diagram

The first iteration was reviewed in a number of meetings and workshops, involving either single or multiple stakeholders at a time. Due to the scale of works each stakeholder was responsible for, the ideal scenario would have been to engage the stakeholders individually, however, several working groups had already been established. These working groups understood the need for system integration, but had no plans for how to implement it across various stakeholders. Through these meetings stakeholders began to engage with the diagrams and understand the benefits of agreeing and formalising this information. All major project stakeholders suddenly had clarity of other projects key deliverables and interfaces. This helped them to understand the relationships with other projects and their own accountability in terms of the implications and impacts of potential changes in project scope or schedule, where these may not previously have been considered. Prior to the development of the migration plan, various stakeholders had made changes to key delivery dates which were not properly communicated to other stakeholders. Those changes impacted the ability of other projects to deliver on time and meet milestones. The migration plan also helped to visualise the amount of work that was assumed and unfunded. This led into further investigation of unfunded works and what was 'missing' but required to enable operation of the new corridor and realise its intended benefits.

Over 20 iterations of the migration plan were produced over an eight month period, following stakeholder comment and feedback. During this period, there were peaks and troughs for stakeholder engagement and feedback. These were typically due to major project changes introducing issues to the migration plan and whether feedback from stakeholders was actively facilitated.

Update diagram
Release diagram update
Stakeholders propose changes

As the rail corridor migration plan continued to develop and mature through repeated iterations, it became apparent that the change in network configuration, through the introduction of a new corridor, heavily impacted the other rail corridors on the network. This impact was not being appropriately captured or understood, highlighting a need for a holistic understanding of key configuration states (corridor specific milestones) and network stages (network wide milestones, usually achieved through the completion of several configuration states) for the entire Melbourne Metro rail network. Key stakeholders had also expressed a desire to use the migration plan format to assist with other network views, such as other corridors and the network as a whole, due to the benefits found from the use of the first corridor migration plan. This enabled the development of a second, network-wide, migration plan.

This new diagram focused on defining the high-level configuration states for the rail network, and understanding which key deliverables or projects enabled major timetable changes and the realisation of other benefits for the network, such as uplift in passenger demand, increases services, network reconfiguration (including new corridors). The list of stakeholders was revised, with some new organisations and disciplines engaged and others removed, to ensure the information displayed on the diagram was at the appropriate level. The same data storage was used and expanded upon in the development of a second migration plan diagram. As the majority of stakeholders were already familiar with the style and benefits of the diagram, engagement the second time was significantly easier; although data gathering and interactive review sessions were still required, stakeholder feedback and willingness to provide information was easier.

Information to be captured

Information stakeholders

Design a diagram

Discuss with stakeholders

The first iteration was developed by estimation and reference to government documents and plans for the transport network. Stakeholder engagement and review was also managed differently to the first migration plan. These were conducted one-to-one, as the network wide diagram required a more intensive review process; this included understanding the entire rail network, what benefits were

Estimate information values
Populate diagram

Review diagram

trying to be realised, how these were being achieved or enabled, and the agreement of configuration states and network stages. This migration plan had over 10 iterations that were produced over an eight month period, following stakeholder comment and feedback. Fewer iterations were required than with the first migration plan as the second contained only high-level information.

Update diagram
Release diagram update
Stakeholders propose changes

Following the acceptance of the first two migration plans, a further four migration plans were developed for other rail corridors, detailed network wide views, and other transport modes (e.g. trams). The use of an iterative diagram development process at PTV facilitated a considerable improvement in stakeholder interaction, and helped highlight areas of uncertainty whilst provoking information accountability and providing a *single source of truth*.

Moving forward

The use of a data-driven diagrams, combined with the implementation of integrated information management across multiple diagrams, is a significant initial step towards the delivery of a complete MBSE approach to systems engineering. Indeed within both case-study organisations there is a movement towards the more formal use of MBSE.[21]

[21] Fabrice Lestideau. Deployment of model based systems engineering into large organisations: Reasons, objectives, means, results PTV application to the victorian public network, 2018

This progression will replace the spreadsheets and basic database structures used to manage the diagram data and replace it with a specialist MBSE tool. Diagrams may be replaced by MBSE tool outputs where applicable; however caution is advised in this area, particularly in non-traditional SE domains, as standard MBSE type outputs (SysML or similar) may not provoke the level of stakeholder engagement required – particularly where they are expected to be used by non-engineering staff, such as higher level management. Exporting from the MBSE tool into other software is a solution that is currently available, although this creates an extra step in the update process. In the near future the options for direct linking between bespoke diagramming tools and MBSE tools is expected to improve, particularly with the introduction of visualisation as a distinct component within the Object Management Group's specification for SysML version 2.[22]

[22] Hedley Apperly. Sysml 2.0 update, May 2016

Within the process description reference has been made several times to its integration within an overall configuration management environment. Where this is already in place it is expected to fit in well; however, in organisations where systems engineering is not fully mature, and the proposed engagement approach will be most beneficial, it is often the case that configuration management policies and processes are similarly undeveloped. In these situations careful implementation of information management as part of stakeholder engagement can also be used as a platform for more widespread adoption of good configuration management practices. The effective implementation of configuration identification, change control and baselining processes, even on a local scale, will facilitate the diagram iteration process; particularly in terms of defining accountability for diagram information content.

Conclusions

A process has been proposed that uses diagrams as a stakeholder engagement tool to iteratively review and update a set of information. Variants on this process have been used effectively in a large number of high profile systems engineering programmes, where it has shown to provide a number of benefits. Two examples of the use of the process in rail programmes have been given and the progression from this process into more formal MBSE methods has been discussed.

The case studies have demonstrated the following benefits from applying the process:

- the diagrams were used as the single source of truth by stakeholders;
- the process reduced siloed working and encouraged collaboration;
- there was an increased level of stakeholder engagement and *buy in* compared to prior to the process;
- the diagram and process brought the areas of uncertainty into focus and helped to close gaps in knowledge;
- the process highlighted critical interdependencies and interfaces that required stakeholder attention;
- the diagrams stimulated conversations and generated interest;
- the released diagrams recorded a clear baseline of project progress at a point in time;
- the process prompted the development of stakeholder working groups to ensure delivery of future configuration states remained achievable and controlled through change management;
- the process developed stakeholders understanding of systems engineering practices and reinforced the need for systems engineering on complex projects.

The impact of the process relies on the adoption of the selected diagrams by the stakeholder community. Only once the stakeholder come to view the diagrams as their *source of truth* for the information will the feedback loop become an automatic process. Getting to this point requires both clever diagram design and careful stakeholder management through the early stages of the process. This is as much an art as it is a science and relies on the experience and expertise of the engineers involved.

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