An Overview of Systems Engineering in the Australian Transport Sector

By

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Abstract

The application of Systems Engineering (SE) principles, processes, and practices has been steadily increasing within the Australian transport sector. The Systems Engineering Society of Australia (SESA) has recently made efforts to bring together individuals working within the Transportation domain to further improve the visibility of SE, to share experiences and good practice, and to support the career development of SE practitioners. This article assesses the status of SE in the transport sector. The outcomes from a recent industry workshop concerning the Maturity of SE in Transport are summarized, confirming the interest in SE and highlighting shared challenges for the domain. Sets of observations written by sector practitioners from different Australian states are provided to give a cross-sectional view of the SE practices being employed in the Australian Transport sector. Conclusions are drawn and recommendations made for both the sector and SESA.

Introduction

This provides an overview of Systems Engineering (SE) in the Australian Transportation sector, with the objective to allow the sector (which has developed differently across different states) to learn from each other and at the same time to provide the Transportation Working Group (TWG) of the Systems Engineering Society of Australia (SESA) an understanding of where it can best focus its efforts to achieve its objectives.

This article provides a high-level overview of the implementation of Systems Engineering in the transportation sector for most of the states in Australia. It does this by focusing on 3 key success factors identified in an evaluation of the application of SE in the Infrastructure sector in the Netherlands [1].

1. Transport related SE Standards and Procedures, their implementation in contracts
2. Senior Level Support for the implementation of SE
3. SE Skills & Training both for Practitioners and Management on both delivery and client side.

Based on our analysis there are not many formal evaluation studies of the application of SE in the Australian Transport sector. Therefore, this article uses assessments by systems engineering practitioners in the different states to provide an evaluation based on their professional experience. In order to also provide some international benchmarking and learning, the article includes a high-level assessment of the implementation of SE in the United Kingdom and the Netherlands, where the implementation of Systems Engineering in the Transportation sector is relatively advanced.

The article is not comprehensive in its review of the transportation sector, nor in its coverage of all overseas practices – we anticipate future coverage. The objective is to initiate a conversation, to exchange knowledge, and to create synergies at a national level.

SESA

1 July 2020 saw the inauguration of the new executive committee of SESA. This new executive committee, led by SESA President John Nasr, also has a new structure with distinctly new type of roles including a Chief Value Officer (Helen Williams) and national domain leads, including a Domain Lead for Transport & Cities (Ruben Welschen). The new national domain-led structure (Figure 1) is a departure from the previous organizational division of state branches; with the objective of using the domain knowledge and domain networks to provide even more value to the members in that domain.

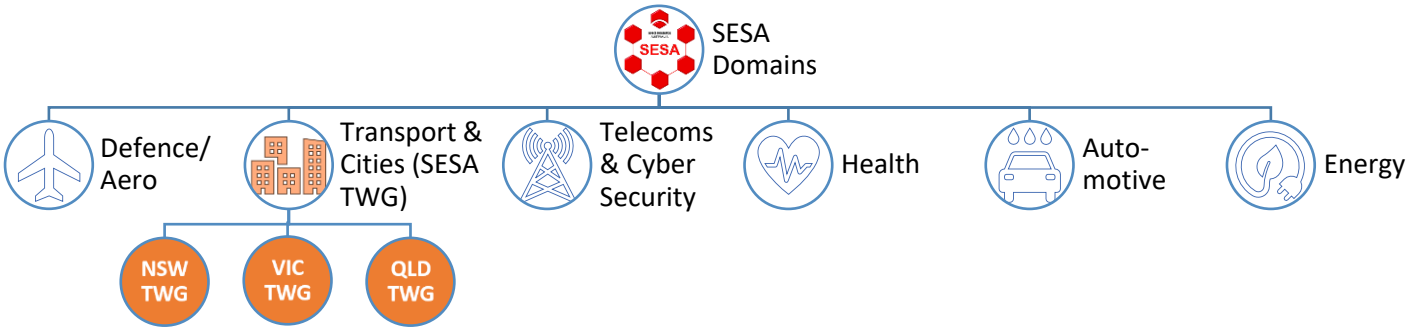

Figure 1: New SESA Domain-led Structure [2]

SESA Transportation Working Group

The SESA Transportation Working Group (TWG) aligns closely with the INCOSE TWG (SESA being the Australian chapter of INCOSE), however the scope of the SESA TWG is broader than the charter of the INCOSE TWG. The current SESA TWG objectives [3] are:

1. To provide a focal point for dissemination of systems engineering knowledge within the broader transportation sector in Australia.
2. To contribute to collaboration in systems engineering practice, education and research in the transportation sector.
3. To improve the professional status of all persons engaged in the practice of systems engineering within the transportation sector.
4. To encourage governmental and industrial support for research and educational programs that will improve the systems engineering process and its practice in the transportation sector.

Within the SESA TWG, there are currently three state based working groups focused on bringing together individuals within each state for specific events and sharing of state-nuanced knowledge and experiences; New South Wales (NSW), Victoria (VIC), and Queensland (QLD). The objectives of the state TWG's are now being aligned and, partially due to the COViD19 situation there have been more nationally broadcasted events.

Panel Session on the Maturity of Systems Engineering in the Australian Transport Sector.

On the 27th of October 2020, SESA organized the Australian Systems Engineering Workshop (ASEW) [4] including a Panel session about the maturity of Systems Engineering in the Australian Transport sector. The session had 95 attendees, facilitated by the author of this article and Four key speakers presented their views:

- Anne O'Neil, Systems Engineering Catalyst & Strategist from the United States of America.
- Andre Hefer, A/Associate Executive Director, Systems Engineering & Assurance, Sydney Metro.
- John Nasr, President, Systems Engineering Society of Australia.
- Owen Traynor, Systems Integration Director, Cross River Rail Delivery Authority.

The following general observations were made:

- There is a noticeable increase in the uptake of Systems Engineering in the Transport sector, partially due to the Authorized Engineering Organization (AEO) framework in NSW
- Transport requires added Systems Engineering, due to the complexity of transport networks and integrated transport solutions, and many stakeholders and users' requirements.

In relation to maturity the following observations were made:

- Better application of SE is required for needs assessment and procurement.
- There is a focus on assurance and process, rather than solving the problem.
- There is a need to upskill and integrate Systems Engineering with existing roles.
- There is a need to activate informed executive sponsors.
- The safety regular can play a role in clarifying expectations for early phases and for laggards.

This article is a natural progression to further document the level of implementation of Systems Engineering in the Australian Transport sector.

General Observations

Interest in the application of SE in the Australian transport sector has gradually increased as a solution to the challenge of managing complex and multidisciplinary infrastructure projects [5]. Although the SESA Transport & Cities Domain Lead was only appointed in July 2020, TWG interest groups in some states were already existent for several years. In 2012, the NSW TWG was setup and in 2013 Systems Engineering got a significant boost when the Asset Standards Authority (ASA) [6] commenced operations on 1 July 2013 and mandated a system engineering approach for Authorized Engineering Organizations. Victoria followed with the establishment of a VIC TWG early 2017. Late 2020 SESA set up a TWG in Queensland. At the time of writing the TWGs combined have more than 30 active volunteers.

In comparison with the Defense Industry which has a nationally consistent procurement process, SE in transport has thus far developed per state. The Office of the National Rail Safety Regulator emphasizes the importance of SE in its Safety Message [7] and its Major Projects Guidelines [8]. And the Rail Industry Safety and Standards Board has published some SE related guidance such as the Guidelines Systems Safety Assurance [9], Human Factors Integration [10] and AS 7473 Complex system integration in railways [11].

Within the Transport Sector, Systems Engineering is primarily applied in the Rail Sector, but also more and more in the Road sector. Intelligent Transport System (ITS) projects in the road sector typically apply an SE approach. Austroads, a collective of Australian and New Zealand transport agencies, representing all levels of government, identified the adoption of a systems engineering approach as a key success factor in the successful incorporation of operations in the design process [12]. In 2014 Austroads developed a report on the Procurement of ITS which used a system engineering approach to define the relationships between the phases of the system lifecycle. Austroads is currently developing a National ITS (Intelligent Transport Systems) Architecture which is listed as a priority action in the Policy Framework for ITS in Australia 2012. This work has included an assessment of international ITS architectures, development of a context and vision, and an initial business architecture. Next steps include establishment of formal governance mechanisms and extension of the Australia's context. With increasing road congestion, constrained infrastructure and the escalation of autonomous vehicles and technology on the roadways, private and public road operators in Australia are recognising the need to adopt a systems approach.

In terms of research, there is a small, but expanding body within academia that are focused on applying systems approaches and SE to the transport sector. For example, the SMART Infrastructure Facility of UOW (University of Wollongong) utilizes systems modeling & simulation for transportation applications. The Human Factors and Sociotechnical Systems group (University of the Sunshine Coast) applies systems thinking methods to safety in transport and infrastructure and Deakin University has used systems mapping expertise to develop the Smart Rail Route Map. SE research projects in transport have tended to be industry focused and funded. Funding avenues include contract funding directly through individual businesses as well as through collaboration with industry-wide bodies such as the Australasian Centre for Rail Innovation (ACRI), RISSB, Australian Railway

Association and the Office of the National Rail Safety Regulator (ONRSR). Although individual SE projects have in the past been funded as part of larger government funded research centres, there is no national agenda for SE research, and the current economic climate sees more dependence on industry funding (regardless of sector).

Training in Systems Engineering has become more prevalent in the Australian Transportation sector. SESA members deliver a short course in "Systems Engineering Tools for Delivering Transport Projects" through Engineers Australia's professional development (PD) provider Engineering Education Australia (EEA) [13]. Many businesses who have committed to SE have also developed in-house training or bring in external PD through training consultancies and academia (see individual state sections below for more specifics). Within academia there are a limited number of universities providing SE education offerings. SESA recently published a list of SE training available on their website [14]. For example, UOW teaches SE within their Masters of Engineering Asset Management from a rail context (since the lecturers are performing research in rail). UOW have also been brought in to provide short courses to rail operators in introductory SE, and more recently Model Based Systems Engineering introductory courses for Sydney Trains and QLD Rail.

New South Wales Observations

In NSW, the creation of the ASA in 2012 has had the biggest impact by placing systems engineering at the center of how projects should be delivered for Transport for NSW. It resulted in 15 SE standards and guidelines [15] which provide detailed guidance for the application of Systems Engineering. The ASA developed and delivered Systems Engineering 101 training to staff and industry creating awareness of the discipline of SE and the inherent benefits of the approach.

Over the years we have seen an improvement in the specification of SE requirements in NSW public transport contracts, and it is now TfNSW established practice to prepare and submit a Business Requirements Specification (BRS), Concept of Operations, and System Requirements Specification (SRS) at key TfNSW network asset assurance and configuration gateways. The application of SE is scaled and tailored according to the level of novelty, complexity and risks. There is ongoing effort to achieve consistency of application via the SE Steering Committee and Community of Practice, as the application of SE principles & practice remains variable. Requirements analysis, functional analysis and agreement of verification & validation during the system definition review are common for Rolling Stock projects but not for infrastructure projects. This significantly affects the quality of infrastructure specifications, the clarity of verification criteria; and causes issues late in the project lifecycle affecting either the time, cost or benefit of the project.

Model-Based Systems Engineering is being increasingly applied to develop the Operational Concept, Maintenance Concept, as well as functional, physical and behavioral models and architectures for complex system delivery programs, including the Digital Systems Program and Sydney Metro.

Work is progressing to align Systems Engineering and Digital Engineering (DE) practice, by appending DE model metadata to requirements schema as a delivery project progresses, to ensure traceability from the system solution back to the SRS, and ultimately to the BRS. This will also facilitate improved whole-of-life asset management decision-making many years after system acceptance.

In the wake of the recent bushfires and floods, TfNSW is strengthening its asset resilience approach, and the Asset Resilience Strategy has adopted the INCOSE Systems Engineering Book of Knowledge Resilience Engineering concepts and guidance as an element of this approach. The strategy also adopts a System of Systems approach that considers the relationship between natural systems (i.e. the climate and weather system, as well as the ecosystem) and human-engineering systems (i.e. the transport system and its logistic supply chain).

Application of SE in complex roads programs is on the rise, with the Western Harbour Tunnel project adopting a strong SE-based approach and the establishment of a Development Partner that is the Systems Integrator or "guiding mind".

The government has recognized the benefit of the SE approach in the planning, specification, delivery and maintenance of systems, and this is apparent in the asset management and asset attestation

requirements and outcomes expected by Treasury and Infrastructure NSW. The recent restructure of the TfNSW organization has seen a growth and repositioning in SE roles, including the creation of a team of systems engineers who are deployed across transport projects and provide advisory services.

There is still a lot to do to achieve a better level of maturity, particularly in the phases prior to procurement. These changes are the beginning of improving the application of SE across transport projects.

Victoria Observations

The Victorian transport network is currently undergoing significant changes, not just from a development/management point of view but also triggered by an unprecedented influx of investments in major infrastructure projects.

2019 saw a major governmental restructure aimed at integrating various agencies into a unified Department of Transport. This mammoth merger brought several challenges; one of them being to re-engineer ways of working across the newly formed Department. As such (at the time of writing this article) most of the new processes and policies that relate to Systems Engineering are currently under development.
Processes that were established prior to the formation of DoT are still being followed by delivery agencies to deliver on their existing commitments.

The application of SE in the transport industry in Victoria is not only happening for project delivery, but also in the establishment of strategies and long/mid-term transport plans through the use of enterprise SE, notably with the establishment of an integrated framework with a whole-of-departmental lifecycle at its center that stems from an innovative blend of Asset Management and SE [16].

Major infrastructure projects in Victoria are embracing the idea of setting project objectives through requirements early in the lifecycle and developing architectures to help manage the integration effort. However, the project teams are still structured mostly around disciplines and work packages which sometimes makes it difficult for systems theory to offer significant value.

SE is being well supported by executives across the Victorian transport system and its value understood, especially amongst supply chain and project delivery agencies. Having said that there is now an increased realisation that clients and contracts must take a more holistic and integrated view throughout the lifecycle and not just in development.

A training “Introduction to Systems Engineering for Public Transport” has been provided in Victoria in 2019 by Engineering Education Australia. The Victorian DoT has an SE Capability Specialist, in charge of uplifting DoT staff on SE competencies, has recently released an SE Wiki portal (Figure 2) in the DoT intranet and provided generic SE training to more than 150 individuals across all divisions.

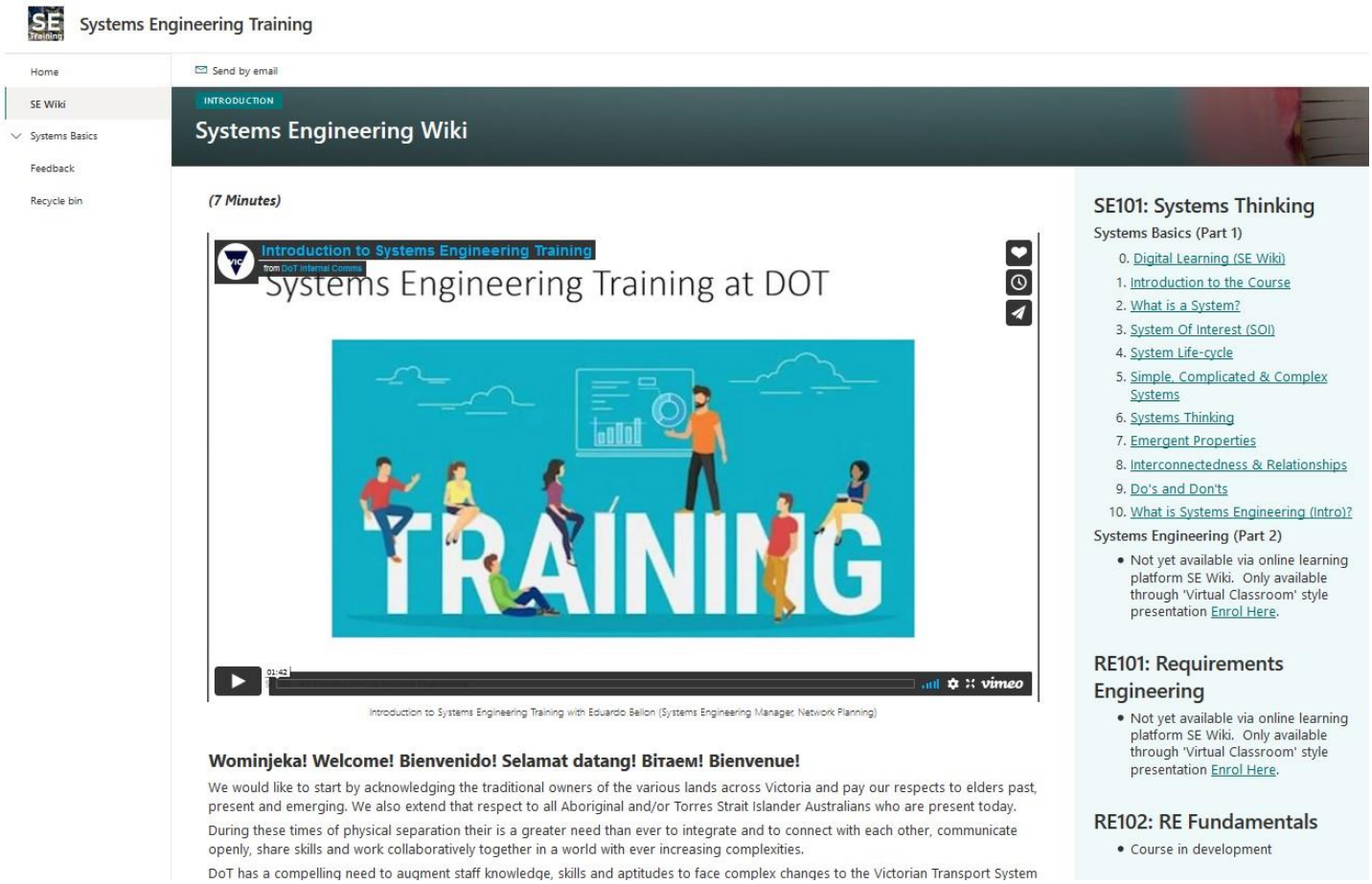

Figure 2: SE Wiki Portal for DoT

Queensland Observations

From an industry perspective there has been a definite increase in SE activity within the Queensland transport sector. Major rail projects have shown an interest in demonstrating adherence to an ISO 15288 approach. However, projects are often applying SE at the assurance phase rather than using it to understand the problem space. However, there are pockets of work being done in Brisbane to understand how the procurement side integrates with other aspects of SE.

There appears to be a recognition that things have to change and that the industry can't just keep doing things the way they've always done". Railways are evolving and systems which were once 30 plus years in the ground are now upgrading at a far faster rate. Bespoke solutions and late changes in the design equal cost and or time overruns. And the advent of cyber threat with more digital systems means a consistent approach to developing processes and interfaces requires a more holistic (System of Systems) approach to be taken.

ONRSR is taking a more proactive role in driving the application of SE in QLD rail projects. And senior management levels are supporting SE as a means of providing a better view into delivering these complex transport systems. DTMR however, is the most influential stakeholder in the introduction of SE for all Qld Transport Modes.

A training "Systems Engineering Tools for Delivering Transport Projects" has been provided in QLD in 2019 by Engineering Education Australia. In QLD there are two university courses for Systems Engineering:

– Bond University – Systems Thinking & Management Modelling for Projects [17]

– James Cook University – Introduction to Systems Engineering and Project Management [18]

Western Australia Observations

The Public Transport Authority of Western Australia (PTA) is currently developing the application of Systems Engineering to support the delivery of rail projects across the metropolitan area. There is pressure on Perth's rail industry to deliver a complex METRONET program. Challenges in applying a systems approach to meet assurance requirements to support projects to deliver successful integrated solutions are evident and a framework to provide further guidance is under development.

Systems Engineering is still in its infancy at the PTA, but its development is supported at all levels of the organisation which appreciates the positive impact applying an integrated SE approach on projects can have in achieving successful outcomes. A Systems Engineering Steering Group has been established to identify and agree the strategy in the development of PTAs systems engineering approach to drive the enhancement of PTA's current procedures whilst ensuring consistent delivery of projects and asset management in alignment with requirements and PTA's Safety Management System.

Training and focused workshops have been introduced to further develop the competency of key engineering roles appointed to deliver projects and to date over 150 individuals from PTA and supply chain have attended Engineering Education Australia's 'Systems Engineering for Public Transport' to drive a consistent approach to Systems Engineering across the PTA and the wider Rail industry.'

South Australia Observations

The adoption of a Systems Engineering methodology appears to be in its early stages at the SA Department for Infrastructure and Transport (DIT). DIT has recently published their first version of a Systems Engineering standard in April 2020 [19] which "describes the implementation of the Systems Engineering (SE) framework which forms part of the Rail Commissioner's Safety Management Systems and Processes against which Rail Accreditation has been awarded by the Office of the National Rail Safety Regulator (ONRSR)".

Current DIT projects however do not show significant uptake of Systems Engineering. By way of example, the DIT Master Specification [20] does not specifically include a Systems Engineering Management Plan, although does require Contractors, in their Design Management specification, to comply with "AS15288, ISO/IEC 29148 and ISO/IEC 26702". Furthermore, DIT tenders and panels do not explicitly request Systems Engineering as a core service.

The Netherlands Observations

The Netherlands has implemented SE nationally in the civil infrastructure sector for well over 15 years now and has been held up as an example of good practice of SE in infrastructure. The Netherlands has followed a different path for its Civil Infrastructure sector than that used in Australia. In the Netherlands a single set of National Systems Engineering Guidelines [21] and procurement practices have been adopted by ProRail, The Dutch Rail Infrastructure Manager, The Directorate General for Public Works and Water Management and a variety of industry associations. The accompanying Dutch version of the website [22] contain a wealth of guidance in Dutch as well as information about Systems Engineering education.

ProRail and the Directorate for Public Works and Water Management have integrated SE requirements in their contracts and administered them accordingly. Research of the implementation of SE in the construction sector in the Netherlands notes that "SE is closely interwoven with all other management aspects and should be treated as such, by implicitly adopting SE in the work processes [23].

In the Netherlands national infrastructure projects commonly risk-assess the compliance demonstration of individual requirements during the tender phase and requirements which are considered high risk by either the client or the delivery side are discussed as part of consultative processes during the tender.

United Kingdom

Across transportation sector in the UK, Systems Engineering processes are defined, mapped to formal standards such as ISO15288 and used on projects and programmes to aid in the clarity of definition of requirements, specification of solution and delivery of assurance. In December 2020, The UK Institution of Civil Engineers (ICE)

published a report titled: “A Systems Approach to Infrastructure Delivery”[24], to address mega-project cost overruns as well as increasing use of complex technology in infrastructure as well as to reap the benefits from the use of Building Information Modelling (BIM) and digital twins.

The UK has examples of cutting-edge strategies of system thinking which are being applied to the Long-Term Strategy of Network Rail. Network Rail through Target 190 [25] is developing efficient interaction with industry to help reduce the cost of signalling from 415K GBP to 190K GBP per Signalling Equivalence Unit. This is the UK’s instantiation of the Reference CCS Architecture (RCA) [26] being developed in Europe. The work being produced via Target 190 relies heavily on the development of an Enterprise Architecture and System Engineering. This work is being shared with industry to help deliver new improved and streamlined processes.

Alongside Network Rail there is the UK Rail Safety and Standards Board - Whole System Interface Committee (WSIC) [27]. It is focused on understanding whole of industry issues and systems to better inform industry wide decisions and programmes. The WSIC think in systems terms and believe in the necessity of translation to enable the wider business and industry to engage in the Enterprise Architecture without the modelling overhead.

There is definitely a growing level of Senior and Industry support and this is being driven by the costs of signaling being unsupportable at current levels. We see with the High Speed 2 project that BIM and the upskilling is forming a fundamental move forward. And we see this in the ICE report: “A Systems Approach to Infrastructure Delivery”. Training and updating of skills is essential and we can see that clients are now moving toward prescribing Systems Engineers in their contracts.

Conclusions & Recommendations

Based on the initial assessment there appears to be insufficient formal evaluation of the application of SE on Australian Transport Projects to provide an in-depth analysis of the application of SE in the states and territories of Australia.

- ➔ *The sector would significantly benefit from further research and an SE evaluation framework covering the full lifecycle (pre- and post- delivery contract) such as that used in Dutch Evaluation Studies [1] to get a nationally comparable evaluation of the application of SE on transport projects. SESA intends to work with national and state government bodies and research institutions to facilitate this happening.*

NSW has developed detailed guidance for the application of SE. Other states are still in the process of developing application-level guidance for the transport sector. However, large transport infrastructure project historically have not performed requirements analysis, concept phase verification/validation and functional analysis as is common during the system definition review of large rolling stock projects. There are efforts to apply SE processes prior to the delivery phase, but there is a tendency to focus on the SE during the delivery phase.

- ➔ *Infrastructure projects should apply good practice Systems Engineering including requirements analysis and client-side validation. A national framework for evaluation of SE on transport projects will further highlight these issues. The infrastructure sector could learn from SE processes in the Australian Defense or Rolling Stock sector or from the Dutch Civil Infrastructure sector.*

The transport sector lacks national direction in the application of SE compared to the defense sector or national guidance provided in other countries. The ONRSR mandates SE but detailed guidance and/or direction on the procurement side is not prevalent or mature.

- ➔ *SESA will advocate with national and state government bodies to establish further national direction, expectations and guidance.*

Given the increased interest and identified need for implementation of SE in the Australian transport sector, there is a significant SE skills shortage in the sector. In some countries and Australian states, government led initiatives in skills and training development facilitates the change to SE based working, whilst in other states it is primarily left to the industry.

➔ *To enable the transition to a more systems engineering based way of working and development of SE skills and capability in the industry, short term government initiative in skills development is required.*

Further Work Required

As with all good research, this article also identified the need for further analysis:

- Formal evaluation of the implementation of SE on Transport projects in NSW and other states
- Further analysis of the application of SE in Transport in other states such as Canberra, South Australia and Western Australia.
- Evaluation of the application of SE outside the rail sector requires further assessment.
- Comparison of good practices of SE in Transport in other countries could be expanded
- Detailed comparisons of the application of SE in other domains could developed.

List of Acronyms Used in this Paper

Acronym	Explanation
AEO	Authorized Engineering Organization
ACRI	Australasian Centre for Rail Innovation
ASA	Asset Standards Authority
ASEW	Australian Systems Engineering Workshop
BIM	Building Information Modelling
BRS	Business Requirements Specification
DE	Digital Engineering
DIT	Department for Infrastructure and Transport
DoT	Department of Transport
INCOSE	International Council on Systems Engineering
ICE	UK Institution of Civil Engineers
ITS	Intelligent Transport Systems
NSW	New South Wales
ONRSR	Office of the National Rail Safety Regulator
PTA	Public Transport Authority of Western Australia
QLD	Queensland
RCA	Reference CCS Architecture
RISSB	Rail Industry Safety & Standards Board
SE	Systems Engineering
SESA	Systems Engineering Society of Australia
SRS	System Requirements Specification
TfNSW	Transport for NSW
TWG	Transportation Working Group
UOW	University of Wollongong
VIC	Victoria
WSIC	Whole System Interface Committee

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About the Author

Ruben is a Systems Engineering Manager with over 18 years' experience in the transport systems, infrastructure and rail sector in Australia, Asia and Europe working for Government, Operators, Delivery Organizations and Consultancy; Ruben established one of the first systems engineering frameworks and implementations for TfNSW's Transport Projects Division in 2012 and was one of the founding members of the NSW Transportation Working Group. Ruben is currently the Transport and Cities Domain Lead of the SESA Executive Committee for 2020-2022.

The article co-authors are members of the State Transportation Working Groups, plus other experienced Systems Engineering professionals from states across Australia.