Systems Engineering the Supply Chain: Multiple Perspectives from Transportation

Moderator: Anne O'Neil, PE, CSEP, MTA New York City Transit, USA

Panelists: Mr. Aaron C. James, Sr., Federal Transit Administration, Office of Program Management, USA

Mr. Brian Halliday, UK Network Rail, UK

Mr. Lori Katzman, MTA Long Island Rail Road, USA

Mr. Jon Hulse, P.Eng, Parker & Associates, Delcan, Canada

Mr. Bruce McDonald, Bombardier Systems Division's Centre of Competence for Mass Transit, USA

Abstract

Transportation services and projects are delivered by multiple organizations and therefore effective systems engineering on these projects must traverse organizational boundaries. Each of the organizations across this complex supply chain faces different issues – and therefore needs to tailor its systems engineering to cope with difficult problems. However, to deliver effective transport services to customers, this systems engineering needs to be integrated.

So how do we systems engineer the supply chain to enable effective, cross-organizational systems engineering? What roles should customers and suppliers take in the overall SE program? What are the key challenges we need to address to deliver the low cost, reliable, environmentally-friendly, high capacity and safe transport services our customers want to use?

The panelists will explore these questions from different perspectives – from designing national transportation infrastructure to building trains. We'll hear from five perspectives:

- National government's transport administration - focusing on keeping people moving in our major cities and getting a decent return from investment in major enhancements
- Rail agency – focusing on integrating infrastructure, vehicles and command and control to deliver effective transport services
- Major rail system upgrade program – focusing on delivering major enhancements with minimum cost and risk
- Systems consultant – focusing on specifying the procurement of integrated systems to meet agency's business needs while navigating sub-system supplier capabilities and systems integration risk
- Sub-system supplier – focusing on delivering vehicles, infrastructure or command and control solutions that meet the market and specific customers need

For each perspective we'll explore: What are the primary systems challenges? Which aspects of systems engineering add most value? What aspects cause the greatest difficulty? What changes would make the supply chain more effective?

Audience discussion is sought to explore:

How does the experience of the transportation industry SE compare or contrast to other industries? Are the viewpoints of various contributors common? Are interdependencies being overlooked?

Biographies

Moderator

Anne O'NEIL, PE, CSEP

As Chief Systems Engineer for New York City Transit (NYCT), Anne O'Neil is improving capital project delivery by integrating a systems engineering approach. This requires changing the agency's business process – from how projects engage project stakeholders, to viewing projects as integrated systems. It has also necessitated building SE awareness at an industry level – among peer transit properties, design consultancies, contractors and suppliers.

Anne joined NYCT in 2002 as Principal Communications Engineer for new subway expansion projects. She directed conceptual and preliminary design for all communications infrastructure and system applications, from customer information systems, safety and security systems, to remote monitoring and control systems supporting operations and maintenance staff. An engineering consultant prior to NYCT, Anne began her career as a control systems engineer in the power industry; she moved to the transportation industry, with the emergence of the intelligent transportation systems (ITS) field. Her responsibilities have spanned the design and construction phases of projects – where she has served in technical engineering design, technical management and construction management capacities.

A registered Professional Engineer, Anne attained CSEP certification in 2009. An active member of INCOSE, she co-chairs the Transportation Working Group and serves as a member of the Commercial Steering Board. She also chairs the American Public Transportation Association Systems Engineering Subcommittee.

Panelists

Aaron JAMES has served as the Director of Engineering, at the US Department of Transportation, Federal Transit Administration, for nearly 4 years now. He is responsible for overseeing, from a national perspective, all engineering and construction-related activities involving fixed guideway transit, bus and other major transportation facilities and equipment funded by FTA. Additionally, he is responsible for FTA's Project Management Oversight (PMO) Program, which performs reviews and assessments of active major capital projects totaling nearly $16 billion.

Aaron has been a member of the transit industry for more than 31 years and has served the industry in several capacities; including design and systems engineering, manufacturing, consulting and industry trade association. He worked closely with numerous transit agencies in the U.S. and assisted them in the development of design and performance specifications, systems integration, reliability demonstration testing, quality assurance and safety certification for vehicles and train control systems. He received a U.S. patent for a signaling receiving apparatus he helped to invent to improve train communications.

He is a member of the American Public Transportation Association Major Capital Investments Subcommittee and the Systems Engineering Subcommittee.

Brian HALLIDAY has 35 years of wide ranging experience in the field of Systems Engineering & Reliability Engineering. During the seventies, working within the Systems Design Group of Hawker Siddeley Aviation, he was involved in the design of the HS146 and A300 Airbus aircraft undertaking a wide range of safety, reliability, maintainability, and support cost studies for those designs.

Subsequently, he worked as RAMS Manager for Hunting Engineering, a major Defence Prime Contractor, and was responsible for those aspects on all of the Company's development projects, many involving complex high integrity systems. He also provided specialist support to external customers in the Defence, Aviation, Nuclear and Rail sectors.

In 1997 Brian joined Railtrack, now Network Rail, and applied his considerable experience as the Systems Engineering Manager on the £10bn West Coast Route Modernisation programme. He currently leads Systems Integration & Analysis effort across major enhancement projects, including development of programme requirements, system analysis models, compliance management and system certification.

Lori KATZMAN is the Long Island Rail Road's (LIRR) Executive Director – Program Administrator for the MTA's East Side Access (ESA) Project. She has over 22 years of progressively responsible capital program management experience at the LIRR and the MTA Capital Company. The ESA project is a major expansion of the LIRR, and will serve approximately 120,000 daily passenger trips, through 3 route miles of tunnels, into a new passenger terminal located beneath NYC's historic Grand Central Terminal. For 8 years, as Director-Engineering Management, Lori was responsible for design involving four railroad/transit properties (LIRR, AMTRAK, Metro North and NYCT), tunnelling and heavy civil construction, and all aspects of railroad engineering. Lori is currently responsible for ensuring ESA Operational Readiness, which is the LIRR's support and activities from design, construction, testing and commissioning through asset/operations turnover and training to achieve revenue service.

Jon HULSE is a P.Eng, Electrical (and Electronics), with over 25 years engineering experience. For the past 15 years Jon has specialized in system engineering and integration, and engineering management in Transit. Background includes communication and control systems, and communication based train control systems for many global turn-key automated transit projects. Jon is currently Chief Engineer for Parker and Associates (a division of Delcan). Previously as Chief Engineer for York Region Rapid Transit Corporation, Jon was responsible for the Region of York's rapid transit capital projects, including BRT systems and subway development. Prior to that Jon also held positions as Manager for Automatic Train Control, and Director, Engineering at Bombardier Transportation's Total Transit Systems Division.

Bruce MCDONALD is the Manager of System engineering for Bombardier Systems Division's Centre of Competence for Mass Transit. Bruce has over 19 years experience in the design, supply, installation and testing of automated rail transit systems including project experience in Turkey, Korea & Canada. Bruce's background is civil engineering and his early experience focused on the systems integration of E&M and Civil works, as well as the supply of wayside elements such as track work & power rail subsystems. His recent experience has focused on the delivery of integrated E&M systems for automated transit projects worldwide for Bombardier's Systems Division, including his role as Manager, Vehicle & System engineering for the Yong-In LRT project in Korea scheduled for completion in 2010.

Panel: "Systems Engineering the Supply Chain: Multiple Perspectives from Transportation"

Position Statement: Aaron C. James, Sr., Federal Transit Administration, US

Federal Transit Administration (FTA) Profile

Dedicated to delivering results that matter to the American people, the FTA supports, improves, and promotes effective public transportation, the Nation's fastest growing mode of travel. FTA supports the development and construction of subway, light rail, commuter rail and bus systems through the administration, management, and oversight of over $10 billion annual grant program, to help communities provide travel choices, improve access to jobs and health care, drive economic growth, and protect the environment.

What are our Business Challenges?

A major challenge for FTA currently is the funding of new major capital transit infrastructure projects to meet increasing demand while at the same time providing funds to assist transit providers in maintaining their assets in a "state of good repair". In 2007, a group of Senators, including then Senator Barack Obama, asked FTA to conduct a study to determine the infrastructure needs of our country's largest rail transit systems. FTA released the Rail Modernization Study in April 2009, which identified a backlog of roughly $50B (2008 dollars) to bring 7 of the nation's largest rail systems to a state of good repair (SOGR) and an additional amount of almost $6B annually to maintain a SOGR after the backlog is addressed.

Maintaining the nation's transit assets in a SOGR, assuming that major funding is available, presents several additional challenges:

- How to develop an industry accepted standard definition of SOGR and measure it?
- What should be the major components of an asset management system?
- How do you assess the physical condition of the nation's assets and rank them equally?
- How do you prioritize which assets to fund first to bring them to a SOGR?
- How do you collect and maintain data on assets conditions?
- What is the trade-off between investments in SOGR and savings in operations/other capital costs?

Which Aspects of Systems Engineering add most value?

From the FTA perspective, good systems engineering would go a long way towards solving the SOGR problem the transit industry faces. Too often transit assets do not receive the needed attention due to a number of factors. Aside from funding, these may include a reactive versus a pro-active approach to system maintenance; lack of or reliable tools for forecasting the condition of transit asset; lack of a skilled labor force; little institutional knowledge/operational experience, and uncontrolled system growth.

Systems engineering can add the most value in solving the SOGR problems in the following ways:

- Thorough systems testing in a simulated operating environment under real load conditions and in the field.

- Define a process for predicting and monitoring useful life cycles of rail and bus facilities and rolling stock for varying operating environments (terrain, weather conditions, duty cycle, mixed fleet/mixed systems operations, etc.).
- Identify optimum inspection and maintenance intervals and repair or replace equipment before it becomes a problem, if economically justified.
- Identify how to achieve the best return on maintenance effort based on a holistic system operations perspective.
- Structure a training program that uses automation and today's technology to keep labor force skilled in the most needed areas.
- Design tools that are easy to use and maintain system performance data.
- Develop a real-time system for predicting and measuring system reliability.
- Maintain a knowledge management system to ensure that lessons learned are captured and available to anyone with a need to know.
- Build a national transportation network to fully integrate the nation's transportation modes.

What aspects of Systems Engineering cause the greatest difficulty?

Applying systems engineering principles early in the project development phase is difficult for many Federal grant recipients because the return on the investment is not always obvious and often the time spent is viewed as a delay as opposed to time savings in the end. Based on this experience one of the most difficult aspects of applying systems engineering is dealing with the perception that it takes too much time.

One tool that FTA uses is a risk-informed project management process to oversee major capital projects. This approach uses system engineering techniques to identify project risks and assess risks to inform the funding decision. Initially applying FTA's risk management tools was difficult because many grant recipients did not appreciate the value added during the earlier years. Risk assessments performed by FTA in the past 5 years have yielded good results – almost too good to be true. In other words, because some predictions significantly exceed cost projections by prospective grant recipients the predictions are hard to believe. But over time the predictions have served the agency well and are expected to get better as the data samples become larger.

Through organizations such as INCOSE the industry can overcome the difficulties of applying system engineering by getting industry leadership to embrace system engineering principles.

What changes from a SE Perspective would make the Supply Chain more Effective?

Establishing system engineering processes that the industry can agree upon for certain modes of transportation would alleviate the need for individual procedures on a case by case basis, which drives up the cost of equipment without necessarily providing the intended benefits. FTA has proposed using performance measures for the industry in its Advance Notice of Proposed Rulemaking for project management of fixed guideway projects. Establishing performance measures for all members of the supply chain, including grants making agencies, project sponsors, suppliers, and operators would certainly help achieve the broader goals of providing safe, efficient, reliable and cost effective transportation for the riding public. FTA looks forward to the industry's participation and suggestions in its new Project Management Rulemaking process.

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Position Statement: Brian Halliday, Network Rail, UK

Network Rail Company Profile

Network Rail (NR), which employs 30,000 people, owns and operates Britain's rail infrastructure; its key roles include:

- Operations – Planning, Signallers, Integrated Control, Railway performance
- Asset Management - Maintenance and Renewals of
    - 20,000 miles of track
    - 40,000 bridges, tunnels and viaducts
    - 1,100 signal boxes
    - 2,500 stations mainly leased to train operators
- Enhancements - infrastructure projects to re-design stations and remove network capacity pinch points

What are our Business Challenges?

The demand for Rail within the UK is now at a 50 year high, with the last 10 years showing a 40% increase in passenger kilometres and a 60% increase in net freight tonnes kilometres. This growth is forecast to continue, driven by economic growth, rising fuel prices and increased road congestion, and increasingly by greater environmental and sustainability awareness.

Network Rail has the national mandate to deliver a railway fit for the 21st century. Over the next five years it will be spending over £34bn across the UK network, delivering improvements in safety, performance, capacity and availability. Recognising that the rail network is approaching the limits of its capacity both Government and Industry are supporting major enhancements to the UK Rail System Capability to provide a Safe, Reliable, Efficient and Affordable future railway.

The business sees adopting a 'systems approach' as essential to meeting the current economic challenges and the expectations of all our customers and stakeholders. We need to become more efficient and deliver even greater value; some specific targets to be achieved by 2014 include:

- Delivering increased capacity through £12bn worth of rail infrastructure enhancement projects.
- Increasing train punctuality to record levels (92.6 per cent of trains on time measured over a year)
- Reducing disruption to passengers by 37 per cent.
- Reducing costs by a further 21 per cent – on top of the 27 per cent savings already achieved since 2004.
- Improving safety still further by reducing the risk of death or injury from accidents on the railway for passengers and rail workers

What is the Current State of Practice for Systems Engineering within Network Rail?

Government and Industry agreed some ten years ago to adopt a staged development life-cycle approach referred to as GRIP (Guideline for Railway Investment Projects) where:

- Projects are broken down into 8 stages reflecting the significant business and technical milestones

- The overall approach is product-driven and each stage is required to deliver an agreed set of products to defined quality criteria
- Emphasis on front-end options identification and selection
- Stage gate reviews test a project's progress

The universal acceptance of GRIP by all levels of the supply chain has provided a strong platform for the development and application of Systems Engineering (SE) processes, techniques and tools. Particular aspects of SE with regard to the supply chain that have proven to add most value include:

- Establishment of multifunctional teams to lead the identification, selection and development of project Options against high level functional & performance requirements. Whilst NR lead these activities, engineering companies and suppliers are typically engaged to provide specialist services as part of a virtual team.
- Use of Systems Capability modelling (e.g. trains and passenger capacity, traction power, reliability) to support options identification and selection as well as for design verification.
- Development of a standardised Programme Specification for each project covering Operational, Layout Design, Engineering and Process Requirements. This specification includes a Engineering Deliverables List that identifies what design documentation products has to be approved during each GRIP stage; the review and agreement of this list with the project delivery teams has aided clarity and consistency
- Requirement for SE to issue a Railway System Design Certificate as part of the GRIP stage gate review process. This serves to highlight any key areas of non-compliance or project risk, enabling timely resolution
- Establishment of a Systems Integrator team on large complex projects, that involve changes to trains and industry operating rules as well as new infrastructure systems, to ensure all interfaces and interactions are understood and managed

In addition to infrastructure enhancement projects a systems approach is also playing a major part in other business transformation initiatives aimed at meeting the business challenges set out above. These include key programmes aimed at reducing costs and improving reliability:

- Modular designs (e.g. Stations, Switch & Crossings, Signalling)
- High Output plant (e.g. track & ballast renewals, overhead electrification installation)
- Intelligent Infrastructure (Train borne measurement and fixed asset remote condition monitoring)
- Signalling control integration
- Route Asset Management Plans – improved maintenance and condition-led renewals linked to performance criteria

So what are the challenges of applying Systems Engineering in the Supply Chain?

Much has been achieved over the last ten years towards embedding SE through the supply chain. However, it is recognised that certain aspects continue to prove challenging:

- Sustaining sufficient numbers of people with the necessary SE competencies has proved difficult; both at Network Rail and within its Suppliers. For its part NR has increasingly brought SE expertise in-house and has also included specific SE skills within its overall Engineering Competency Framework.
- Whilst NR requires an SE approach by its Suppliers, as called for in the Programme Specification, the response has been found to be variable reinforcing the view that insufficient competent SE resources are being deployed.

- There can still be a tendency towards the 'traditional' rail approach of each discipline individually demonstrating strict compliance to its associated mandatory national rail engineering standards; but with too little attention given to ensuring that the integrated solution delivers the required outputs (e.g. train capacity, performance, sustainability)
- Following on from the above; Suppliers have often been slow to understand the importance of system design verification activities against output functional & performance requirements. It is acknowledged that the fact that NR often runs many of the system verification models, based on Suppliers design inputs, does not help this situation.
- Understanding system interfaces and interactions has long been a challenge within Rail infrastructure projects; not least due to the linear nature of deployed systems with changing configurations and legacy systems. Various attempts have been made to establish standardised formats for understanding and managing the system configuration of railway infrastructure. Approaches have ranged from UML based models to CAD based layered schematics. This aspect is currently the subject of an UK industry-wide research project.

So what would make the Supply Chain more Effective from a SE Perspective?

Given the perspective and challenges outlined above there are certain areas where an improvement would likely contribute to a more effective supply chain.

- Improving the liaison with Suppliers at the earliest stages to ensure SE process requirements are fully understood. In a recent innovation project all technical and project management staff, both Network Rail and Supplier teams, were brought together for an introduction on the principles of a Systems Approach and the supporting SE processes to be used.
- Currently, Compliance Matrices (the central mechanism used for recording V&V evidence) generated in the DOORS environment are typically converted to Word for Suppliers to complete prior to re-import. Notable exceptions are some major projects such as London's Crossrail where all parties in the Supply Chain are required to operate in a DOORS environment using a ComplyServe application. Network rail is also currently upgrading to the Web-Access version of DOORS to allow greater access by all Suppliers to requirements and V&V information.
- SE processes in support of major projects have now matured to a point where both Suppliers and NR project management should be able to recognise a clear and consistent approach. Hopefully, this will lead to SE becoming fully embedded into everyone's day job. There are further opportunities for industry wide liaison within the UK to promote a common approach reflecting best practise. UK Department of Transport, Network Rail, London Underground are all active members of the UK INCOSE Rail Interest Group (RIG) together with Suppliers and Academia. The current industry working group looking at System Architectures is a good example of this.

Panel: "Systems Engineering the Supply Chain: Multiple Perspectives from Transportation"

Position Statement: Lori H. Katzman

Background

East Side Access is a major expansion of the Long Island Rail Road (LIRR), and will serve approximately 120,000 daily passenger trips, through three route miles of tunnels, into a new passenger terminal located beneath NYC's historic Grand Central Terminal. This expansion program involves four railroad/transit properties (LIRR, AMTRAK, Metro North and NYCT), tunneling and heavy civil construction, and all aspects of railroad engineering.

Primary Challenges

From my perspective in the supply chain, as the owner's representative on this major rail system expansion program, the challenges with respect to Systems Engineering can be categorized as follows:

- The nature of a major rail system expansion having significant duration and cost

- ESA epitomizes the term "System of Systems" with:
  - Individual Systems – some as simple as lighting and plumbing
  - Interfacing Subsystems and Integrated Systems – including traction power SCADA; signaling and train control; customer information signage and public address system;
  - The Railroad as a System – all systems and infrastructure operating to a set of performance criteria for revenue service
  - Legacy System Interfaces – new systems integrated into the existing LIRR systems, which are also evolving
  - Multi-Agency Integration – Amtrak and the LIRR, in the busiest interlocking in North America ("Harold" interlocking), integrated with the new ESA systems, with the same issues of legacy and evolution.
  - All happening simultaneously for a cut-over into revenue service

  - ESA requires the input, support, and most importantly, the buy-in of many users across multiple jurisdictions, including railroad engineering disciplines (ie. signals and traction power), maintenance departments (ie. right of way, structures, train equipment) and train operations

  - External Factors, subject to change over the duration of the program including:
    - Technology shifts/improvements
    - Construction constraints - i.e., availability of civil elements
    - Contract packaging constraints - i.e., market conditions, resource availability, bonding capacity and system interfaces and integration requirements

Systems Engineering – What Adds the Most Value?

The focus is to deliver the project on time, within the budget and to identify and manage the risks. An approach that is sensible, methodical and spans the entire life-cycle of a project would be desirable to any project manager, be it civil or systems.

The approach, as outlined in the "Vee diagram" was of the most value. The "Vee" being the systems engineering graphic which displays the process of defining and documenting needs, designing and building to meet those needs and then verifying and validating that the work was done and that the final products meet those needs.

We tailored that "Vee" and divided it into the typical project phases from planning and design through opening day revenue service. This enabled us to define the activities required along the way and to develop a strategy to implement, verify and validate. It informed the development of the testing program, contract packaging strategies and the management program to validate that revenue service will be achieved. This helped with the challenges of systems engineering over the long term, defining/breaking down the "system of systems" and by gaining buy-in to the approach across disciplines.

Systems Engineering – The Greatest Difficulty

The challenge was to make systems engineering user friendly and to get it out of the stratosphere with text book definitions that were not readily applicable to railroad systems. We then needed to make it specific to ESA, in terms of project management and implementation by defining and laying out the "what, when, how and who". The systems engineering terminology was the first hurdle, which needed to be translated for the railroad and customized to reflect the nuances of ESA. For example, the phrase "testing and commissioning" was not universally understood in terms of scope, schedule and responsibility. We needed to define the periods under the auspices of the ESA project team after each system was tested and the systems were integrated and tested and then the period when the railroad took over maintenance and operation and conducted pre-revenue activities before opening day Revenue service.

We undertook a lot of this customizing on our own because of the difficulty obtaining readily available and local consultant resources with previous experience on major rail expansion projects, who could implement the systems engineering approach, prepare the required project planning documentation and lead the effort. Many systems experts were experienced in train controls, SCADA and the like, mostly hardware and software, or with rail project experience that was on smaller new starts or Design/Build/Operate/Maintain (DBOM) projects. The most applicable rail expansion systems engineering expertise seemed to reside in European consultancies or agencies.

Recommendations / Lessons Learned

The lesson learned from this program is that once the language barrier was broken, Systems Engineering is not "rocket science". It is a logical approach to project management in today's world of complex integrated systems. Gaining buy-in to this approach early allowed us to build confidence with senior management and funding partners. It also brought operations and engineering departments on to the same page so that we could build the specifications, contract documents and operations and maintenance plans.

The recommendation with respect to the consultant piece of the systems engineering supply chain to meet the needs of transportation expansion projects is to have the necessary skill sets available and speak the language understood by those in the rail industry.

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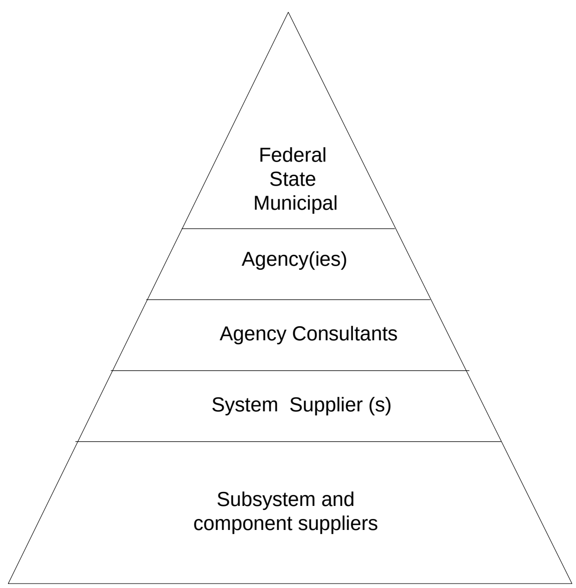
Position Paper: Jon Hulse, P.Eng

The System Consultant's responsibilities in the Supply Chain

System engineering (SE) the supply chain can alternatively be viewed as System Engineering each phase of procurement. For any major transit system project there are several levels in the chain:

1. Funding agencies; there may be multiple tiers of government, each providing funding, and with their own specific or strategic requirements and objectives for the project, and these may define the procurement approach, levels of risk, schedule constraints etc.
2. The transit agency itself, or perhaps multiple if there are requirements for Operations in, or with adjoining agencies;
3. The agency's consultant or consultants, each with specific strengths and experience, but sometimes not always fully aligned;
4. The system supplier or suppliers where there may be joint ventures or partnerships involved, again with their own contractual and organizational interfaces and challenges;
5. The subsystem and component suppliers.

System engineering is often seen in horizontal silos, and depending on where we sit in the supply chain, we each apply system engineering at our own level and then pass the responsibility for the next level of SE to the next link in the supply chain.



Levels of the Supply Chain

The System Consultant must be able to support each level in the supply chain to ensure the transition of scope and responsibilities from one level to another is seamless and follows a natural progression and development of requirements and design. The responsibilities include:

- Supporting the funding and transit agencies in developing system requirements including the required SE activities and processes that must take place both pre and post contract award to ensure that each subsequent step continues leads to the fulfilment of the project needs;
- Assisting the agencies to follow the necessary SE practices in order to identify the project risks and develop the appropriate mitigation measures including the contract documents;
- Provide oversight of the project implementation, at each level of the supply chain, to ensure that the processes, practices and mitigation measures defined are followed, and further developed as necessary to ensure that the project requirements are met; and
- Maintaining knowledge of system and sub-system supplier capabilities and best industry practices.

What are our Business Challenges?

The System Consultant's business challenges often originate in the following areas:

- SE is often added as an afterthought to a project, and so is not truly integrated into the supply chain;
- Integration is required at each level as requirements and project objectives are defined; and errors or omissions at the higher levels can magnify at the lower levels;
- At each level we try to "add value", but by doing so we may:
  - make design decisions that are best made at the next level;
  - sometimes over engineer or incorrectly specify the requirements for the next level of supply.

  As a result we may place unnecessary constraints or introduce errors into requirements for the next level in the supply chain;
- The procurement process may not facilitate a System Engineering approach; for example for a subway tunnel, one contractor performs a geotechnical survey, the client specifies and purchases the tunnel boring machines, another contractor designs the tunnel under a DBB approach, and a third contractor bids and wins the construction contract to operate the tunnel boring machine and build the tunnel. Compared to a design build scenario, with the necessary oversight by the client's consultant (engineering, QA and PM), and a single DB contractor taking on all the risk, the client bears all the risk, including:
  - Incorrect specification of the tunnel boring machine;
  - Inaccuracies in the geotechnical survey;
  - Errors in the tunnel design; and
  - Delays or cost overruns in construction due to any of the above.

Which Aspects of Systems Engineering add most value?

Systems Engineering has demonstrated its value in many industry sectors and provides valuable tools in process and approach to the implementation of large complex projects. The various industry standards, including the INCOSE SE handbook provide guidance on the application of SE and ensure that the whole project is viewed, not as series of disconnected elements, but rather as a complete system allowing:

- Management and development of requirements from all stakeholders
- Identification and management of the interfaces between the various system elements and users;
- Identification, management and mitigation of project risks;
- Validation and verification of system and subsystem requirements.

What aspects of Systems Engineering cause the greatest difficulty?

The implementation of SE across such major organizational boundaries, and under the many competing pressures often leads to the following difficulties:

- The standards, processes and practices to apply SE within and throughout each level of the supply chain may not be consistent, which may lead to overlaps, gaps or omissions;
- System Engineering may not be considered at all at the highest levels in the supply chain, except as something that must be done by the system supplier. If the organisation at any level does not take a SE approach (change management, configuration management, risk management, requirements definition, etc) then this will be reflected in the procurement of the next level in the supply chain. Too often an RFP issued by an agency for consulting services will define the roles and staff required to provide the services, without perhaps adequately defining the level of integration that must be provided by the consulting team. The RFP should therefore request a proposal for a team capable of ensuring an integrated system, while covering the scope of services required;
- System Engineering practices may not be consistently employed to the same degree at the subsystem or component level, except in so far as to satisfy the procurement specification, or "win the contract". Many suppliers promise to deliver on SE documentation, including RAMS etc., but often lack the skills or resources necessary to do so. As a result the system supplier may have to provide training, resources or even take on the work themselves on behalf of the subsystem or component supplier.

As a consequence, we do not always successfully integrate requirements or processes vertically through the supply chain, or procurement phases.

What changes from a SE Perspective would make the Supply Chain more Effective?

In order to make the supply chain more effective some changes should be made:

- Funding and regulatory agencies must lead from the top and ensure that where their money is being spent, the necessary and appropriate SE processes and approach is taken at every level to ensure project delivery, on time, in budget, and without compromise in performance;
- System Engineering practices must be built into the funding organisations and agencies, and reflect the SE approach in their procurement of consulting and other services, and in the system procurement;
- Consultants must demonstrate and practice a truly integrated approach to their Engineering Services;
- System engineering standards and processes must be transparent throughout the project, from one level to the next, with clarity and simplicity, and with any definition of requirements limited only to the level necessary so that artificial and unnecessary constraints are not placed on subsequent levels in the supply chain (i.e. to allow innovation to flourish);
- Some effort must be expended in vertical integration within the project so that stakeholders, agencies, system and subsystem suppliers can connect to ensure that the most effective solutions for system delivery and project execution are facilitated through a joint definition of requirements and interfaces, and the most appropriate apportionment of risks;
- Transparency should be sought throughout the procurement and delivery process so that the development of requirements and the design is as open as possible. This would show where, why and how design decisions are made at each step, and as the project gathers definition providing traceability and accountability.

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Position Paper: Bruce McDonald

Bombardier is a supplier of complete transit systems and is also a supplier of system components such as transit vehicles and automatic train control. The Systems Division core mandate is to use system engineering to provide properly designed, tested and commissioned systems that are fully integrated and meet the overall system requirements. As Bombardier Inc is the largest supplier of transit vehicles in the world, the Systems Division strives to select the optimum configuration for a given transit solution.

The panel assembled for the INCOSE symposium has agreed to focus on the following key questions with respect to the system engineering of rail transit systems

1) What are the primary systems challenges?

2) Which aspects of systems engineering add most value?

3) What aspects cause the greatest difficulty?

4) What changes would make the supply chain more effective?

WHAT ARE THE PRIMARY SYSTEMS CHALLENGES?

The primary system engineering challenge for transit systems is to define the necessary requirements for the system and then to ensure the design of the system meets those requirements. As an overall system supplier, Bombardier is experienced in selecting the correct technology to meet the particular system needs and employing system engineering techniques to ensure the product is properly delivered.

As systems supplier, Bombardier is pleased that prospective clients have taken an interest in ensuring a level and consistent playing field by hiring consultants to ensure the systems engineering approach is followed by all prospective bidders, however, the primary challenge remains to establish only those requirements that are necessary for system performance, but allows the best technology to be selected.

There seems to be a tendency in the procurement of rail transit systems to specify the components of the system in great detail rather than (or in addition to) specifying the required overall system performance. This limits the system supplier's ability to develop an optimum system-level solution.

WHICH ASPECTS OF SYSTEMS ENGINEERING ADD MOST VALUE?

Aspects of system engineering that add value to the transit system development include the use of overall system performance analysis, simulation and modeling to evaluate alternative solutions and allow optimization of the overall system cost/performance ratio, thus ensuring that the system provides the required performance as specified, on schedule and within budget. The use of expertise in system-level interface issues such as availability, maintainability, EMI/EMC, noise & vibration, and wheel/rail interface to ensure that the system performs as required from day one, without the need for any redesign or modification.

Other typical examples where the system supplier has been a key added value to the success of a project include the interface between E&M and Civil scope of work, including alignment optimization, tunnel sizing analysis and elevated structure optimization. Other examples of interfacing within the E&M scope include interfaces between the major scope items including Automatic train control, Power Supply and Distribution, Communications, Vehicle and other mechanical and system design features.

WHAT ASPECTS CAUSE THE GREATEST DIFFICULTY?

Some clients don't understand or appreciate the need for, or value of, systems engineering; so they don't attach sufficient value to systems engineering in their budgeting and bid evaluation criteria. They tend to attach great importance to ensuring that they have the lowest cost vehicles, but fail to ensure that they obtain the best cost / performance ratio for the complete system. Some clients don't even consider the possibility of optimizing the cost of the complete system including civil works, instead using an entirely separate budgeting and procurement process for the civil works, thereby throwing away civil cost savings that could be achieved by taking advantage of a coordinated electrical, mechanical and civil works design.

If a client such as a city government hires a consultant whose primary expertise is in civil engineering (for example) to oversee the specification and procurement of a transit system, the consultant's emphasis may be on the design of massive civil works, with the E&M systems considered only as an afterthought. This type of procurement tends to result in a non-optimum system design.

Depending on the expertise and experience of the consultants involved in a transit system procurement, and possibly depending on the terms of the consultant contract (are they paid by the hour, the page, or some other measurement?), there can be a tendency for consultants to specify the dimensions, design and construction of the vehicles, for example, in great detail, rather than specifying the required system performance. When the vehicles (or some other subsystem) are specified in great detail, it tends to eliminate the system supplier's capability to provide an optimum, cost-effective, system-level solution using his standard products.

WHAT CHANGES WOULD MAKE THE SUPPLY CHAIN MORE EFFECTIVE?

Two key changes that would make the supply chain more effective would include:

(a) A recognition among those procuring transit systems that they should specify system-level performance criteria rather than specifying hardware details, thus allowing system suppliers to provide their optimum system solutions.

(b) The development of better system-level standards that could be used to define acceptable performance levels for transit systems. The ASCE APM standard has been quite successful in establishing an industry standard set of requirements for automated people movers. There is a need for a similar standard aimed at automated metros and automated light rail systems. As an example: one area where such standards would be very helpful, would be if they included the definition of a set of meaningful methods of specifying and measuring system availability. This would avoid the need for consultants to invent a different set of system availability criteria for each project, and would allow the comparison of system availability results between systems, something that is presently not possible in any meaningful way.