# MANAGING COMPLEXITY TO DELIVER TRANSPORT SYSTEMS IN URBAN ENVIRONMENTS

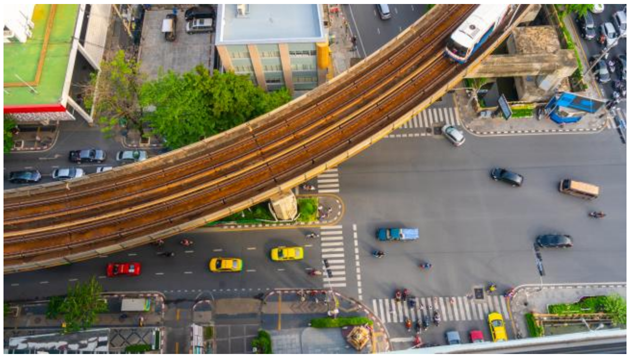
## Three dimensions of complexity to consider when integrating systems that support the sustainability aspirations of communities

Every transportation system has a base level of complexity—a product of the environment in which the system operates and the scope of what the system does to meet operational needs and stakeholder requirements.

Urban transport systems have the potential to range from low-complexity systems such as a network of buses to highly complex transportation systems that consist of multiple interacting modes of transport—from high capacity, high frequency metro-type systems to microtransport options such as bicycle hiring schemes. Each system may be controlled by a single entity or by multiple parties, which range from large, longstanding organisations such as Transport for London (TfL) to relatively new organisations such as Uber.

Additionally, urban transport systems exist within the established built environment, where space is at a premium and there are a number of already established systems and structures. Transport systems generate high interaction and typically bring considerable impact during construction and operation. All these factors create highly complex environments in which to deliver transportation systems.

The complexity of planning for, delivering and operating a transportation system within the urban built environment means the systems engineering practitioner needs to be adept at the assessment of complexity to tailor a systems-focused approach that meets the needs of the client and end user; the practitioner must also be capable of implementing that approach so the end system can function within the given environment.



### *DIMENSIONS OF COMPLEXITY*

#### Urban Environment

Understanding the environment (location) in which the system will be installed and operate is a core principle for any successful project and key for understanding the most appropriate systems engineering approach. Urban environments are highly developed—houses, commercial buildings, roads and bridges support the large population density. Upgrading existing or creating new transport infrastructure is complex because of the need for that infrastructure to operate within and interact with this constrained built environment characterised by multiple structures and interacting elements and activities.

## Open systems

As stated by INCOSE, a closed system is a system that is completely isolated from its environment whereas an open system is a system that has flows of information, energy, and/or matter between the system and its environment and adapts to the exchange. All physical systems of interest to systems engineering are open systems.

When it comes to interaction, the degree of openness drives the overall complexity of a transport system. All transport systems are open to an extent as they have a high level of interaction with other systems and users of the environment (e.g., passengers and operators). Open systems are more complex than closed systems because the interactions with these external elements cannot be fully controlled; therefore the system must be prepared to handle any number of possible interactions. For example, a bus rapid transit (BRT) system must share the road with other vehicles and users, and although they may have dedicated lanes, buses are still affected by the surrounding road traffic. This traffic impacts reliability and availability of the service in a way that is not fully within the operator's control.

How open the system is depends on the level of control over the system boundaries. A bicycle hire scheme is one of the most open forms of urban transport. From pick-up to drop-off, anyone can use the bicycle in anyway and take it anywhere—this makes managing location, as well as the condition and availability of assets a complex problem. By comparison, an underground metro system is less open. Its interactions with outside users and systems are focused at specific locations—the stations—and the train actions and interactions along the route are almost wholly in control of the operator.

## Making Positive Impact on the Built Environment

As well as generating a high level of interaction, urban transport systems will impact the environment in which they operate, both during construction and operation. Disruption to the surrounding built environment is inevitable. For example, light rail transit (LRT) tram systems often use existing roads along the desired route. When installing and constructing an LRT Tram system, sections of the road will need to be closed, existing utility pipes will require re-routing, and street furniture will have to be moved—all before beginning construction and installation of the LRT assets.  Co-ordinated planning is needed to execute the works in a restricted time and space window. Once operational, the LRT will continue to impact its environment, affecting traffic flow and influencing the number of people in the area at any given time. As such, the introduction of urban transport systems can support the sustainability aspirations for the area.

Whilst the system provider has limited control over the environment, the positive impact on the environment can be significant. The role of the systems engineer is crucial in this process, to consider and understand all the factors and stakeholders and how they interact. A well-integrated transport system can reduce the use of cars, thus improving air quality, reducing congestion and enhancing transport access—benefits for residents and local business.

**Stakeholders**

In any transport and infrastructure project, there are sets of stakeholders, each of whom have their own drivers and needs. The government, local councils and other parties are interested in defining the capabilities and the impact on the area. They represent the users of the system and those who will be affected during construction and operation. They will often set requirements and constraints that the system needs to meet, including wider legislation including sustainability targets. Then there are parties that will interact with the system—for example, utility companies and other transport-infrastructure and supporting services. They will be keen to understand the interfaces with the system and may have requirements regarding their interactions. There are also regulatory bodies that ensure the standard of the system is acceptable and safe for use. Although this is a common list for any transport-infrastructure project, the number of individual stakeholders in these categories is often far greater when providing an urban transport system compared to similar infrastructure in other more sparsely populated environments. Managing the relationships and often conflicting goals of these stakeholders adds complexity.

**System**

The system itself creates a level of complexity. Operationally, an urban mass transport system has high capacity, limited downtime and often utilises partial or full automation. To achieve these aspects, the system design must utilise innovative methods and novel approaches to construct and operate a system for its specific urban environment. However, doing something for the first time or in a new way is hard to plan and challenging to execute, which adds complexity into the system and risk into the programme. Balancing the use of novel solutions and emerging technologies with established procedures and products is key to controlling innovation-driven complexity; often, urban environments require a high level of innovation to be viable. For example, an urban metro system commonly has large sections built on elevated viaducts (Dubai Metro), or underground (London Underground) as there is limited space on the surface. This requires sophisticated and innovative planning, design and construction and provides additional restrictions on operation and maintenance.

## *MITIGATING COMPLEXITY*

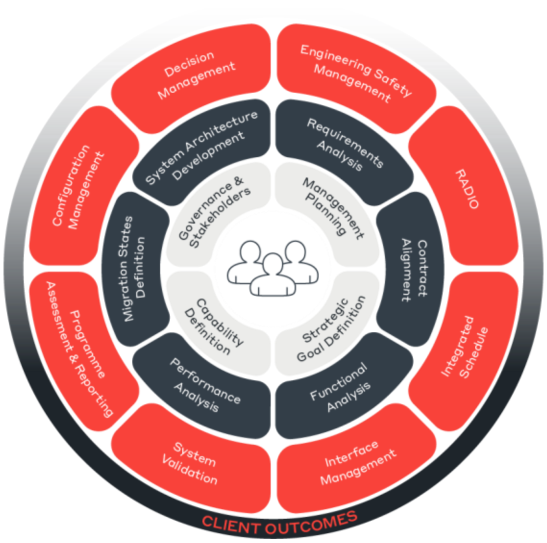
With the urban environment having such a large impact on complexity, it is important to understand how this constrains the delivery and operation of the system. When upgrading an existing metro system (Deep Tube Upgrade Programme for London Underground), the work can be delivered within the bounds and constraints of the existing system and largely within the operator's control. In this case, the key impacts would be system closures, reduced operational capacity, restricted working times and the logistics of moving supplies in an underground environment. As discussed, constructing a tram system has different challenges due to the degree of impact on the existing infrastructure in the environment and with certain activities being outside the development rights and the control of the system implementer.

Systems engineering and integration can drive plans to mitigate this complexity. Systems integration can be tailored to the specific environmental and system challenges, which is particularly important for urban transport systems where the built environment is complex and may constrain the implementation options for the system; this complexity can be managed by understanding the system interactions, focusing on the core benefits, capturing the risks, assumptions and dependencies as well as managing stakeholder engagement and migration planning. These are all core parts of WSP's systems engineering framework—SI:D$^3$.

### Applying a Systems Integration (SI) Framework

SI:D$^3$ (WSP's SI approach) provides a set of techniques and processes that can be tailored to the system and environment complexity. They shape a framework that enables the system engineer to work with organisations on core systems integration (SI) actions:

- develop a robust strategy,
- define and manage the design of the system and
- deliver an integrated solution.




These can be harnessed where applicable to help manage the complexity of the system and the environment. As an example, Governance and Stakeholder Management, Migration Planning and Migration State Definition, and Configuration Management are methods that are particularly applicable to managing the complexity of the urban environment.

**Governance and Stakeholder Management** delivers a defined and collaborative structure reducing programme risks from external and internal sources and provides stability through cycles of change and development by maintaining clarity of direction to the delivery teams and clear lines of reporting and decision making. Delivering and operating an urban transport system involves many parties, and this process helps manage their interactions by driving structured focussed engagement with key stakeholders throughout delivery.

**Migration Planning and Migration State** Definition provides a view of the programme which is easily interpreted by all stakeholders and supports strategic decision making in line with programme objectives supporting planning and securing funding. As discussed, many urban transport systems are built in an environment over which they have limited control and will likely cause disruption to surrounding services, business and infrastructure. By defining migration states and carefully planning the transition between them, the optimal installation or upgrade path can be performed, minimising disruption as much as possible and interacting with key stakeholders at the right time to reduce the time taken.

**Configuration Management** enables the impact of effecting a change to an asset or subsystem to be easily assessed and managed across the whole programme. Cost and schedule can then be controlled by the management of change to targeted key elements. The complexity of the urban environment and the uncertainty driven by innovative solutions is likely to result in change and evolution throughout the delivery and operation of an urban transport system. Configuration management helps manage that change and ensure that the overall benefits are still delivered.

In addition to this, and depending on the particular system, other areas of SI:D$^3$ such as Functional Analysis, Contract Alignment and Integrated Scheduling, can all assist in understanding and managing the complexity driven by the environment and the system.

## Defining the Best Approach

Finding the optimum systems engineering approach requires understanding, the environment, the system and also the client organisation. Having established that systems engineering can help to understand and manage the three dimensions of complexity, the last piece of the puzzle is to consider the capability of the organisation delivering the system. Whilst the system and environment drive which processes are most applicable, understanding the systems engineering maturity of the delivering organisation helps determine which tools to use and how best to apply those processes to get the maximum value.

Assessing client maturity is based on a number of factors, including systems engineering experience, size of the organisation and scope of the programme. A client familiar with the systems engineering approach might use DOORS databases to manage their requirements and interfaces, whereas for another client, requirements can be managed with a simpler, less-connected toolset. Similarly, one client might be capable of adopting a model-based systems engineering (MBSE) methodology in its entirety for a large programme. A smaller, less systems-experienced client may select individual processes to manage specific risks and realise particular opportunities. Establishing the most appropriate approach is key to gaining the advantages whilst ensuring that unnecessary complexity is not added in the application of systems engineering.

The SI:D$^3$ processes and toolset are designed to be scalable and adaptable to enable clients of all levels of maturity to harness the value of systems engineering and utilise the approach to deliver on time and within budget whilst realising all the expected benefits.

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Systems engineering is not just for managing complex systems but also for managing complex environments and complex stakeholder relationships. Urban transport systems have a particularly complex environment for which they are designed and constructed and within which they must operate and be maintained. Therefore, even seemingly simple systems can benefit from a systems-engineering-based approach to achieve success in urban environments, especially today and going forward, as carbon-emissions reduction and accessible transport, plus other sustainability goals, increasingly influence infrastructure programme decision-making.

To explore WSP's systems integration (SI) approach, continue to the SI hub page.

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