

Enabling City Sustainability Through Transport Systems: Moving From Vision to Reality

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Enabling of sustainability performance through transport requires meaningful engagement of the community in the selection of urban form and transport system options and systems engineering to transfer sustainability performance expectations to the physical performance.

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This paper discusses sustainability in relation to transport within cities and outlines some practical methods for enabling this to happen. Greater transparency and integration of process from the community and government vision of a city through to the development and operation of the infrastructure that supports it is the key.

The enabling of sustainability performance through transport requires two challenges to be met. The first of these is the meaningful engagement of the community in the selection of urban form and transport system options. A sustainability framework has been developed providing the context needed for the supporting methodologies.

The second of these challenges is the enabling of the sustainability performance choice at the macro scale phase to flow through to the physical reality of the system. Systems engineering is cast as a practical methodology for enabling the sustainability performance expectations to traverse the complexities through to the physical performance.

1 Introduction

Sustainability has become a fundamental expectation in our societies today. With the experience of growing cities under stress through loss in environmental quality, liveability and numerous inequities, community and governments alike have an imperative to do things better and strive for values and a future vision that has collectively become known as sustainability. The reality of climate change we now face is imposing an overarching new timeframe for sustainability action.

The objective of this paper is to introduce some practical methods for enabling sustainability within our cities to move from visions to operating infrastructure that delivers the sustainability outcomes needed. Specifically this paper introduces how the use of sustainability performance metrics can enable inclusiveness and facilitate involvement of community and decision makers at all stages of urban planning. It also introduces how the systems engineering approach can be utilised in urban planning and infrastructure delivery to minimize the risk of losing sight of the original intent of the plan/ strategy.

The paper concludes that greater transparency and integration of process from the community and government vision of a city through to the development and operation of the infrastructure that supports it, is the key to enabling sustainability aspirations into sustainability responses.

2 Involving Community: The First Challenge

To begin this discussion it is important to recognise that sustainability needs to be able to be defined. Facilitated by the work of the United Nations over the past 20 years,

sustainability is now most commonly recognised in terms of the three pillars of environmental sustainability (or stewardship), social equity and economic efficiency (World Commission, 1987) which frames the principal meaning of sustainability today. An effective sustainability performance requires all three pillars to achieve complimentary outcomes rather than simply individual outcomes.

Community involvement in shaping sustainability strategy is often through participation in visioning and goals setting. For cities, one of the major challenges for sustainability is centred on the urban form, the transport characteristics and the interactions between these and the communities they support. However, when it comes to the question of which scenario should be selected, there is little scope for community to confidently help shape the choice. Without quantifiable assessment methods, the connection between scenarios and sustainability outcomes are extremely subjective to the point where little benefit may come from public discussion. Improving the visibility of these connections for community and decision makers alike would increase the opportunity for better choices.

In a new approach to sustainability analysis (Doust, 2008), a sustainability framework was formulated to bring not only the three pillars of sustainability together, but also a holistic consideration of the urban system, the urban dynamics and the resulting sustainability performance. Figure 1.1 summarises the framework, showing the interconnection between the urban system elements, the urban dynamics and identifying the three pillars of sustainability. This framework lays out the frame points for ensuring that the systems elements and interactions that drive the sustainability performance of the city are visible and measured.

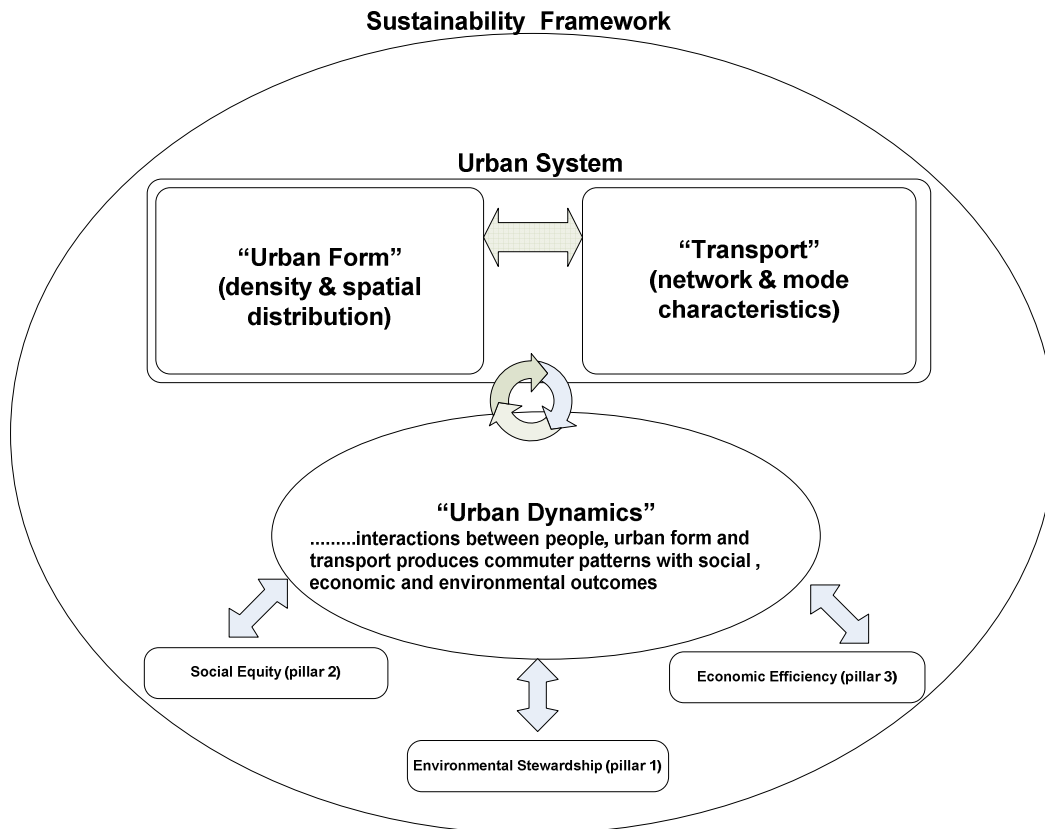


Figure 1.1 The urban “sustainability framework”

The “Urban System” is the physical aspect of the framework, consisting of the “Urban Form” and “Transport” elements which define the structural configuration of the city. Interaction between these two elements shows their interdependencies. “Urban Form” is characterised by density and spatial distribution of land-use. “Transport” on the other hand is characterised by the transport network spatial layout and the specific mode characteristics.

The system function is to provide for the needs of the community (including industry). Response of the community to the “Urban System” produces interactions that result in selection of location of residence and workplace, industry and trips and so on. These interactions are collectively known as “Urban Dynamics”. It is an iterative process as indicated by the circular arrow having feedback effect between each element. The resulting “Urban Dynamics” outcomes generate the sustainability performance in terms of the three pillars included as elements in Figure 1.1. Each pillar has a feedback to the

“Urban Dynamics” and consequently the “Urban System”. This is indicated by the double headed arrows in the figure.

Most cities begin their city’s urban and transport planning with metropolitan wide strategic planning instruments. Involvement of community in visioning often begins at this front end scale. Systems thinking in terms of this framework enables methodologies used by government to be related. This gives greater visibility between the elements and traceability of what factors drive sustainability performance. A case study of Sydney has embodied this sustainability framework with both existing and new methodology to give a useful example of the usefulness of this systems thinking approach at a city wide scale. The case study research added methodology that enables community to be engaged in the optioneering of urban form and transport systems on a city wide scale by the use of a novel approach to visualising the city wide or sub regional sustainability performance effect of each option.

The visualisations make use of the new concept of environmental sustainability – accessibility space. Figure 1.2, illustrates this spatial concept and the idealised performance goal. A city’s sustainability performance in relation to the goal can be analytically quantified and simply visualised in plots for assessing the three pillars of sustainability in cities.

The environmental sustainability measure (Pillar1) can be formulated from many different parameters (e.g. traffic noise generated, ecological stress, particulate emissions, resource usage). For illustrative purposes a measure based on known fuel consumption of vehicles (see Cosgrove, 2003, p342) with speed was used to calculate CO₂-e footprints for motor vehicles. Detailed operational methods were developed (Doust, 2008, Chap 4) and applied to generate a quantifiable measure. Accessibility has been identified as a useful measure in social and economic aspects of sustainability (see Expert Group on the Urban

Environment, 1996; Warren Centre for Advanced Engineering, 2003; Kachi, et al., 2005; Kachi, et al., 2007). Accessibility measures were derived (Doust, 2008, Chap 4) for each travel zone pair. Separate operational methods were developed to generate worker and employer focussed accessibility measures. These are measures that are relatable to social equity (Pillar 2) and economic efficiency (Pillar 3) respectively.

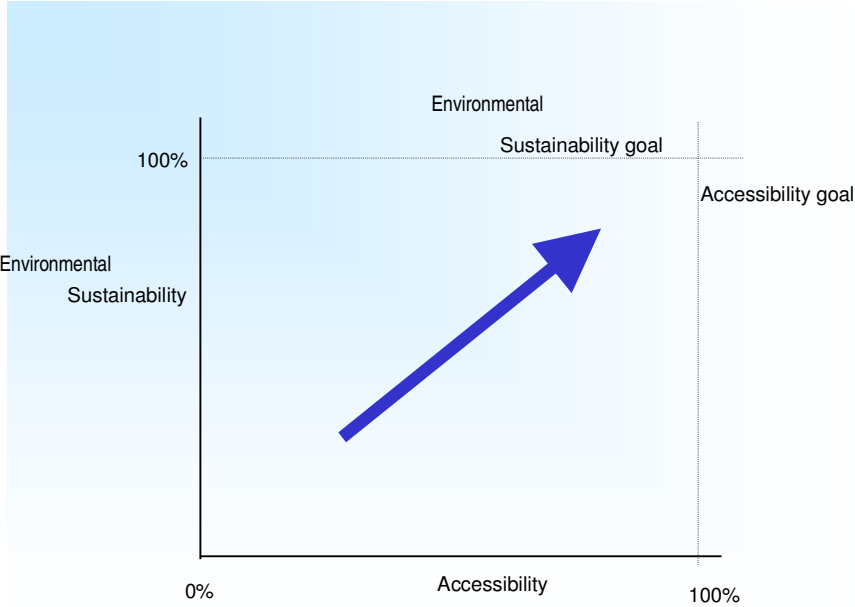


Figure 1.2 Environmental sustainability - accessibility space

The sustainability performance characteristics is judged in terms of data set shape, frequency and spread in the “environmental sustainability – accessibility space”. The following simple example provides the fundamentals for a small number of origin zone to destination zone pairs. The scatter plot shown in Figure 1.3 shows the sustainability performance against the desirable trend in sustainability. A shift to the top right hand corner and a limited spread in accessibility is identified as the theorised optimum.

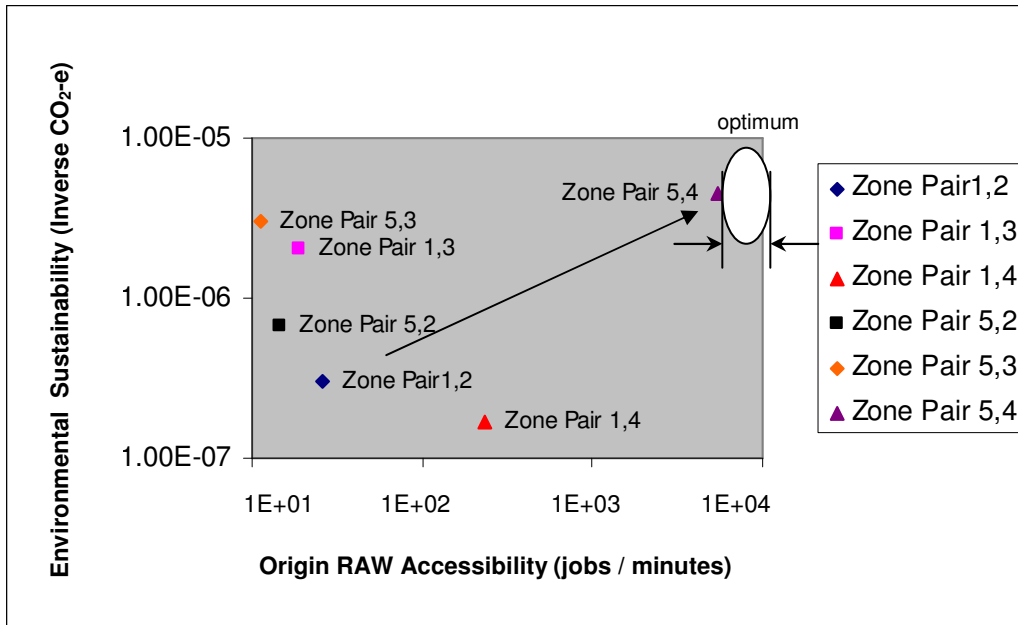


Figure 1.3 Environmental sustainability – “Raw” accessibility (Pillar3) goal

Origin RAW Accessibility is defined as the accessibility to jobs at a destination zone (TZj) from an origin zone (TZi) calculated by dividing the total attractions from all origin zones to TZj by the transport impedance from TZi to TZj. Units are workers/ minutes, where workers are a proxy for jobs.

The environmental sustainability measure is defined as the inverse of CO₂ emissions from the total JTW trips between zone pairs, including an allocation of emissions from manufacture of vehicle and road infrastructure. This is calculated as a sum of the carbon dioxide equivalent (CO₂-e) per unit trip km at the average speed with the shortest path trip length and number of trips. The carbon dioxide equivalent (CO₂-e) is calculated as the sum of the quantity of greenhouse gas and the Global Warming Potential Index (AGO,2005,Appendix 3)

The metrics were able to be determined for large data sets for the Sydney case study (792 travel zones) by systematic analytical techniques using trip tables, network skims and car emission rates as inputs. These techniques have given the metrics a clear

objective basis traceable to the source data. The visualisations although built from many thousands of pieces of data provided a simple representation giving a holistic view of the sustainability characteristics and trends.

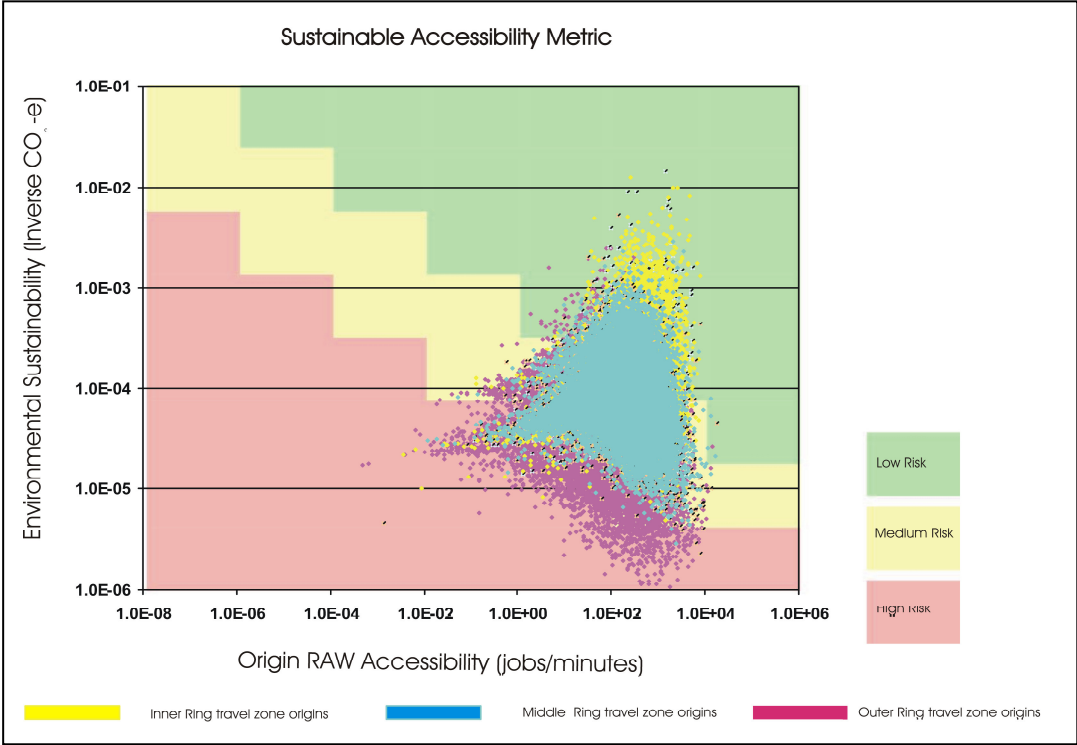


Figure 1.4 Sustainability risk visualisation

These metrics can also be applied in a way that expresses sustainability performance in terms of sustainability risk. High risk, where sustainability performance is poor, is indicated by low metric values. Low risk, where sustainability performance is satisfactory, is indicated by a higher metric value, above a community accepted minimum target. The grid concept can be likened to a risk matrix allowing each zone pair to be assigned a sustainability risk rating (Figure 1.4). The sustainability risk boundaries are specific to each city, and influenced by the population’s estimated resilience. This sustainability risk rating can then be replotted back onto geographic space using GIS thematic mapping. Figure 1.5 illustrates the visual effectiveness of this technique for the outer ring of Sydney, replotting the red coloured points falling in the high risk squares in Figure 1.4

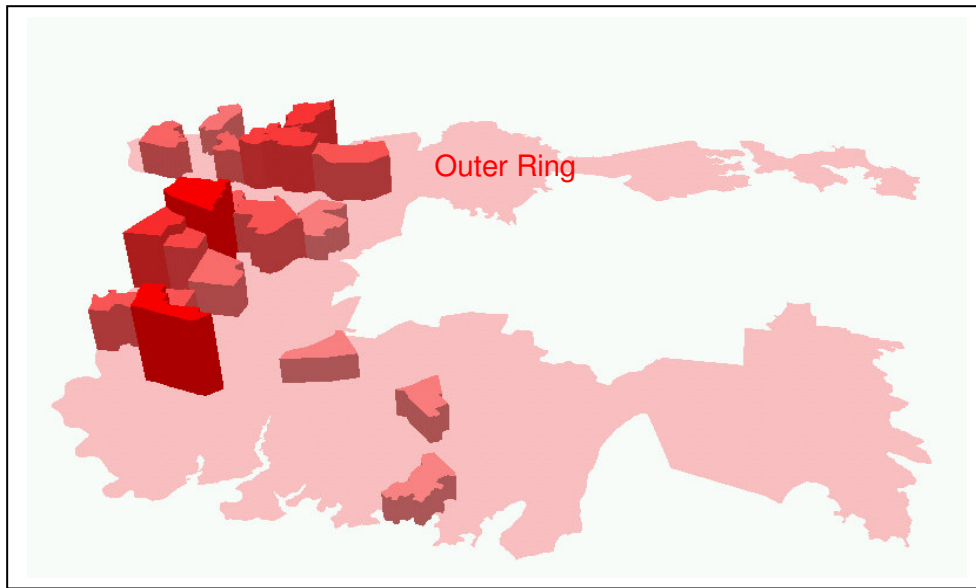


Figure 1.5 Map of High Sustainability Risk in Outer Ring

For community and decision makers these visualisation give a simple snapshot of overall sustainability performance, for each scenario being considered. Change the scenario, produce a new metric plot to see the sustainability effect. Stakeholders can see measurable change for their communities in relation to sustainability goals. The process provides another dimension to visioning and sustainability strategy development by adding the means by which community can measure and judge one transport system and urban form scenario with another.

A particular strength of using the sustainability framework and the metrics demonstrated is that they are derived from data sets that have been used by planners for many years. These are commonplace amongst transport and city planning departments in many cities. With these inputs and the assistance of readily available GIS/T software, all of the urban dynamics and sustainability metrics are able to be derived. The sustainability framework enables the holistic picture of sustainability to be maintained during the assessment process.

An important aspect of the metric methodologies is their analytical basis. All visualisations have traceability back through the algorithms to the source inputs. This is a particular strength when checking results, making scenarios changes and applying different planning instruments. A particular benefit is that it enables community and government to work together in an interactive way.

3 Delivering the system: The Second Challenge

Transport and urban systems from the time of metropolitan strategic plan and masterplan to operations travel through a process of many years duration. Beginning at the point of decision at governmental policy level the goal then becomes that of enabling the physical system to happen. Often this is a different course for the urban form and the transport systems. Depending on the governmental policy, the course may be very hands on through the government agencies empowered to deliver, or it may be a facilitation of guiding frameworks, plans and high level contracts and alliances with the private sector.

In Australia, urban form is steered through various planning instruments which put frameworks and constraints over lower levels of government and private industry which deliver the bulk of the urban land use infrastructure. In some cases the control is held with the agencies of higher levels of government where that land use is of seen to be crucial to how an urban system functions, examples are major growth centres and special employment centres.

Transport systems consist of trunk transport corridors, local feeder corridors, shared or personal vehicles and places to either join or leave the vehicles. Prior to the 1990's, the very hands on approach through the government agencies was the most common deliver and operation model for transport corridors and shared vehicles. However, since that time

a greater variety of approaches are used leaning now more towards facilitation by guiding frameworks, plans and high level contracts and alliances with the private sector.

With the reality that delivering sustainability that the community aspires too, needs to traverse the path of development over many years and through many hands, there is a risk that the original intent can be lost.

There are many elements that need to be in concert for the whole urban form and transport system to deliver good sustainability performance. With multiple agencies involved there is a difficulty in seeing the overall goal and keeping the effort integrated between the agencies. This is complicated further with public private sharing of the delivery effort. Over a long delivery time frame, integration between the teams delivering each development phase is also a significant risk.

However, asset life cycle management principles based on systems engineering approaches provides practical methodology to minimise this risk. The systems engineering process has been used for managing complex engineering projects for over thirty years and has been applied to public infrastructure management in NSW since the 1990's. Most of the experience has been with the management of individual assets at a scale beginning with sub corridor assets.

The principles of systems engineering are centred on identifying system functional and performance requirements, how these are allocated to systems and subsystems, how the design of these systems are aligned to requirements. It involves a holistic approach to managing the increasing maturity of designs, the integration of the design effort and its commissioning. It enables a system that operates in accord with the system requirements and is supported over its life. Visibility of the system requirements and the traceable

pathway of the maturing system alignment to these and realignments are paramount to the method.

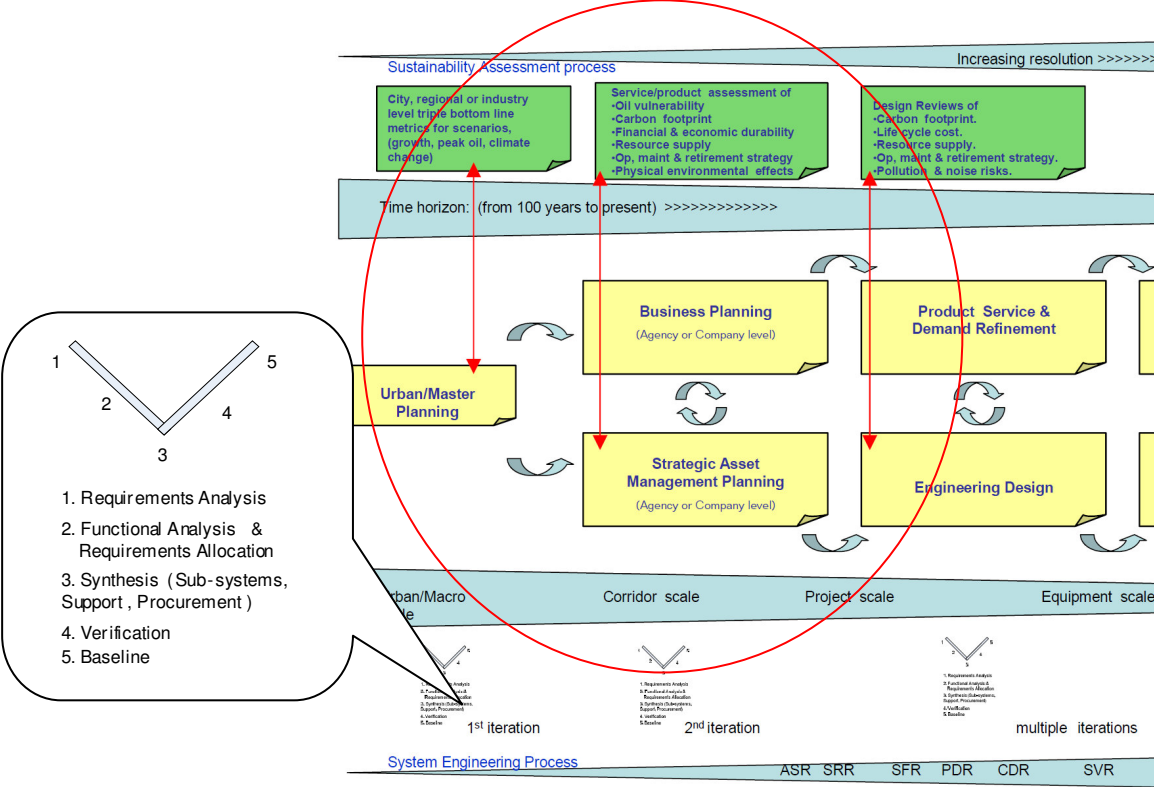


Figure 1.6 Enabling Sustainability

Part of the first challenge for enabling sustainability is to quantify the performance. By definition this requires that sustainability targets for each community are formed around the option of choice in the visioning and optioneering interactions between community and government. These targets are in effect system requirements. Applying systems engineering principles to all the downstream planning phases to this macro scale enables the sustainability requirements and system development to be conducted in a well controlled manner that is widely known to be effective in managing the complexities of asset development at a lower level. The overarching process is summarised in figure 1.6

By firstly identifying the sustainability requirements as functional and performance requirements along with other requirements at the master planning level the urban form

and transport system the process sets about synthesising the system to meet the requirements. It hinges on having good visibility of analysis and traceability of requirements and system baselines between agencies and between business and engineering parts of the business. This develops from the aggregate system down into the disaggregated components of the system. It is characterised by repeating this process of requirements analysis and system synthesis again and again as the system matures.

Urban Rail operators characteristically define themselves as providing transport "products" to meet the needs of its customers, both passengers and Government. The products are made up of its people, fleet, infrastructure and collective packaging to deliver its services. Urban Rail Business can be summarised as:

- Providing transport of people
- Market and deliver rail transport services to meet demand
- Offer services where total income at the least meets the total cost.

Infrastructure is viewed as a supporting component of the overall product, recognising also that infrastructure is a large and long term investment with lengthy time frames needed for making changes. The bottom line of the infrastructure planning process is to match the infrastructure to the business.

In the 1990's, part of the agency level application of system engineering principles was piloted in CityRail NSW as part of the planning of the complete corridor infrastructure for the Illawarra Division. CityRail's total railway network is approximately 1400 km of which 300 km is in the Illawarra Region.

Applying the System's Engineering methodology to the complete corridor infrastructure demonstrated how the process bridged a gap in the business to engineering interface by adding up front iterations of the process at the earliest concept design stage of the planning. A key purpose was to assess strategy options, to determine whether there were better ways of delivering the CityRail product.

System engineering uses a “Vee” cycle methodology, which is an iterative design process of development and refinement through feedback. A mini “Vee” is applied to this phase in a two stage process. Applying the methodology to the complete business segment infrastructure for each corridor at this early stage has a major influence on programme and project alignment to the business objectives. A first stage macro level iteration develops the corridor infrastructure concepts at a high level, to identify and evaluate configuration options before significant resources are allocated to the projects.

Early application of the mini “Vee” process provides visibility to option effectiveness and gives opportunity to realign downstream efforts before significant resource commitments are made. A particular benefit of this stage of process is in building confidence in the appropriateness of the investment in the eyes of the CityRail Management, Treasury and the other government and community stakeholders.

3.1 Requirements Analysis - Macro Level

At this first stage an application of requirements analysis is conducted to draw out from both the non engineering divisions and engineering divisions of the Urban Rail business the stakeholder requirements. Experience has shown that this is best initiated with a process of one on one discussion with stakeholders in the following areas:

- product development sections responsible for transport, train and corridor and timetable planning;
- Operations and fleet, customer services, corporate planning, financial and economic evaluation units, corporate safety and environment;
- Strategic asset management, engineering and infrastructure maintenance.

At this early stage, there is often no collective set of stakeholder requirements. This information is progressively formulated into infrastructure corridor level system requirements (Figure 1.7). The systems thinking approach is used to compile and formulate the often only partly defined stakeholder product requirements into a cohesive set of requirements that the infrastructure is expected to deliver. This work is formulated into an infrastructure system requirements report (Corridor Report) that is verified one on one with the individual stakeholders prior to establishing it as a baseline document.

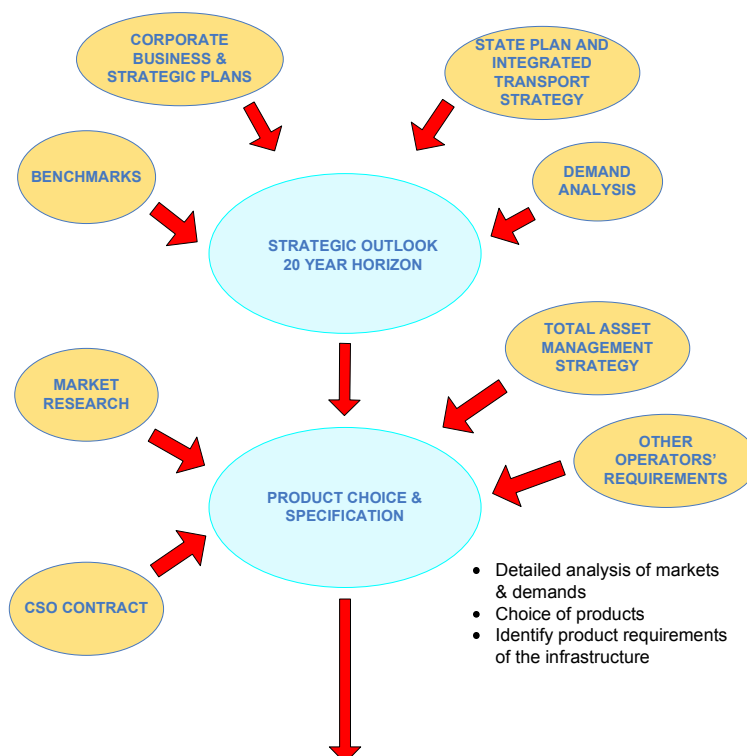


Figure 1.7 Macro Level Requirements Analysis

At this early stage, a qualitative assessment is made on the relationship between generic physical system architecture and the functions they deliver. The system requirements

(product requirements for the infrastructure system) are mapped to the functions and then to each of the physical infrastructure system elements in a Requirements/Functions/Architecture matrix at Infrastructure Level.

The process of requirements allocation is based on what the experts advise is a capability for typical configurations of the physical system. Experience shows that one or two iterations of the proposed requirements allocation with an assessment of system capability to meet the allocation gives a more realistic outcome at this point in the process.

3.2 Target Configurations Synthesis/Trade Off Studies/Evaluation - Macro Level

The process for this Macro stage is summarised in Figure 1.8. Beginning with a strategic diagnosis meeting and including a two-step value management workshop the process includes verification of the allocated functions and system requirements and a second step to formulate options, evaluate and short list target corridor configurations of the System.

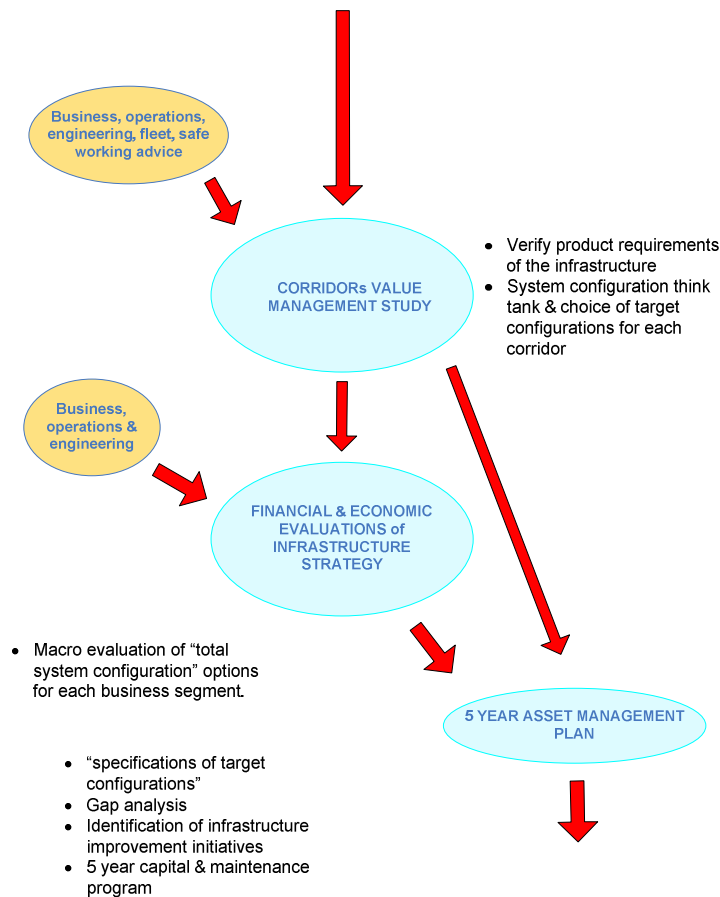


Figure 1.8 Macro Level Synthesis, Evaluation, Trade Off and Verification

The strategic diagnosis is a preliminary meeting to identify the major issues and areas of concern to be addressed in the workshop, and confirm the stakeholder participants and verify the Infrastructure System requirements by the participants.

The next step is to conceive the Infrastructure System options for evaluation. Options for the target configuration are usually already in the mind of stakeholders when this part of the process occurs. Without shifting the emphasis from requirements definition, the question of what options they can see to meet their needs should be asked of each of the stakeholders when the one on one consultation is occurring at the beginning of the Macro stage. Each of these options should be considered where they have some merit and the workshop used to brainstorm other configuration options which may be applicable.

The workshop is then used to facilitate the value management study group participants in the determination of the target configurations. The basis for selecting the preferred target

configurations in each of the systems involves determining the advantages/disadvantages of the options. The group select and weight evaluative criteria (using a paired comparison technique for the weighting) and evaluate the two viable options using the Value Ratio (performance against evaluative criteria divided by cost) to determine the preferred option.

Selection of the target configuration at this stage is founded largely on engineering judgment of the system specialists. This will include actual data on the configuration characteristics and alignment to requirements where it known from other projects.

An important step is to identify packaging of infrastructure configuration changes that have a common business purpose. Looking at the business drivers, the performance requirements and the project characteristics, it is possible to have projects grouped into specific initiatives. Each initiative project has a synergy in delivering a business outcome.

Initiatives developed, include not only the configuration change projects but also projects which implement changes to maintenance and operating processes to ensure the initial value of the configuration change is sustained.

3.3 Verification - Macro Level

The selected options and programme scenarios are subjected to macro financial & economic analysis to test the value of the totality of the selected target configurations against alternatives for that corridor. The analysis differs from the financial & economic appraisal of individual projects, since its focus is to identify a preferred investment programme option with a preferred set of system configurations. This may involve a wide range of individual projects.

The process is repeated for each business initiative as shown in the Figure 1.9

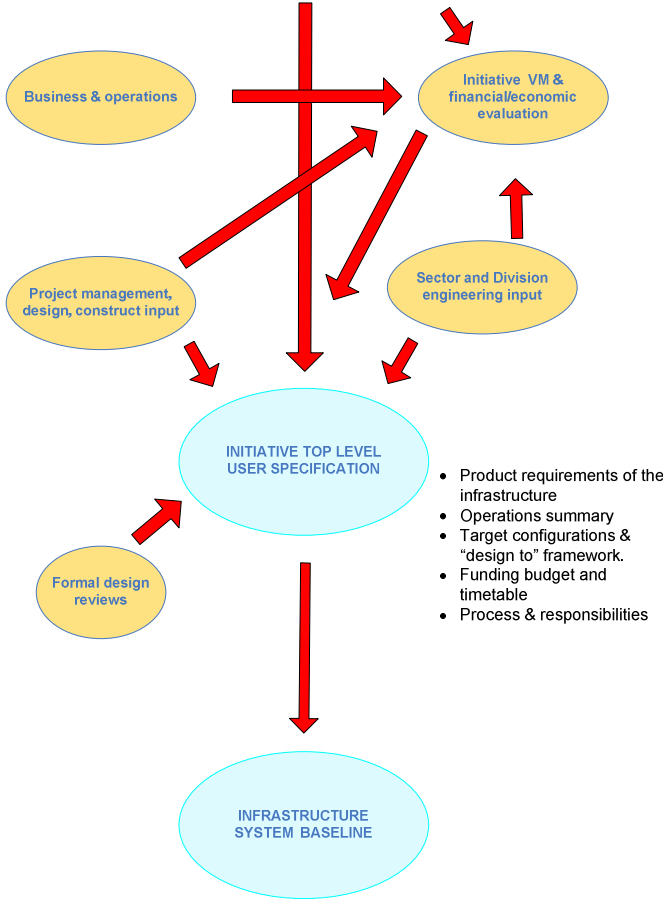


Figure 1.9 Initiative Level Process

The output of this iteration is documented in a new document with the objective of ensuring the delivery of completed projects consistent with the business, operational and infrastructure requirements for which the initiative had been planned.

The document defines:

- Business requirement of the project;
- Operational requirement and constraints;
- Product requirements and configuration of the completed project;

- Scope of works;
- Project funding and program;
- A design framework requiring traceability to the planned outcomes;
- A project management framework for Management plan, Relationships
Co-ordination meetings, Reporting, Project variations, Safety, environment, quality assurance and risk management and Hand over requirements.

This document serves as a base reference for the business client, initiative coordinator, project managers, designers and constructors. It is the basis of a common understanding on how the project is to be carried out. The purpose of the document is to convey the business drivers, performance requirements, configuration baseline data and design development processes expected to be followed by the design and review teams in the next level of design development.

At this point the project management traditionally picks up a project for design development and implementation. The Top Level Specification is also aimed at influencing this process to take on a System's Engineering methodology by specifying a design framework that continues the mini "Vee" process throughout the design and delivery phases of the infrastructure system, minimising the risk of the design intent becoming lost and to establish traceability of design decisions to the functional requirements of the specification.

For the sustainability performance required to become a physical reality, the systems engineering principles provide a promising practical method, enabling the asset development effort to deliver the embedded sustainability requirements with greater certainty across all development phases of the system's development.

4 Conclusion

Enabling sustainability performance through transport requires two challenges to be met. The first of these is the meaningful engagement of the community in the selection of urban form and transport system options. A sustainability framework has been developed providing the context needed for the supporting methodologies. Together with novel visual sustainability performance metrics the basis has been established for a meaningful interactive optioneering process between community and government. The ability to make adjustments to planning instruments and observe sustainability performance at a macro or sub regional level in a short time frame gives the prospect to enable inclusiveness in system choices, not limiting community participation to the visioning of cities alone.

The second of these challenges is the enabling of the sustainability performance choice at the macro scale phase to flow through to the physical reality of the system. The sustainability performance choice made at the macro scale phase is in reality setting the sustainability requirements that needs to be delivered by the physical system when operational. Systems engineering principles used effectively to reduce the non conforming performance risk of complex assets at the project level is cast as a practical methodology for enabling the sustainability performance expectations to traverse the complexities through to the physical performance.

The systems thinking approach in the sustainability framework, the visualisation metrics and the management of the delivery process bodes well for enabling sustainability to happen in reality with out the need for complete changes in the way assets are delivered. This can only be an important factor in a world where climate change issues have accelerated the need to be sustainable.

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