Complexities in mega rail transportation projects

"Sydney metro" and "Melbourne metro rail" insight

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Abstract

Purpose – The purpose of this paper is to initially evaluate the most current and important complications of sustainable mega rail transportation projects. This purpose is assisted by thoroughly reviewing the foremost uncertainties and challenging issues of STI. Once these factors are established, they will be the base of STI indicators. Finally, to consolidate such alignment, the Sydney Metro and Melbourne Metro are then compared and analyzed. The analysis would then create a platform to measure sustainability and relevant complexities in mega rail transportation projects.

Design/methodology/approach – To further consolidate such hypothesis, this research investigated two mega rail transportation projects in Australia. Both Sydney Metro and Melbourne Metro Rail were selected as the basis of case study, as both possess similar sustainability aspects.

Findings – As an outcome this research found that, complexities in both of these projects were based on future challenges and opportunities including imperfect equalization or not balancing all the four sustainability indicators; and where and how to emphasize the overlapping of these four indicators. In summary, these findings can assist the relevant planners, to better prepare and manage mega railway infrastructure and their operations.

Originality/value – While the sustainability for transportation infrastructure has been covered extensively by other authors, this paper strengthens the four specific and separate STI indicators – especially for mega rail infrastructure. Although, there are some crossover areas within these indicators, however, this research separately validates each as an independent entity. Commonly, there are three dimensions within the sustainability domain – environmental, economical and social. Nevertheless, for this research, a fourth dimension engineering which includes all the technical focus, has been separately developed. This is particularly important to effectively deal with all the complexities, particularly for mega projects, such as rail transportation infrastructure. Accordingly, separating the engineering dimension would thus reshape the triple bottom line factors to include a separate technical focus. To further evaluate this separation of the four specific areas, two mega Australian rail transportation projects are then reviewed as experiments.

Keywords Rail transportation, Sustainable transportation infrastructure (STI), Melbourne Metro Rail, Sydney Metro

Paper type Research paper

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1. Introduction

Commonly, sustainability in a universal context, denotes a viable and continual approach of development (Hardisty, 2010; Ahvenniemi *et al.*, 2017; Calvert and Snelder, 2018). Mattsson and Jenelius (2015) also noted that, sustainability is a vital, constantly applied strategy to improve the connection between the environmental and economic objectives. As urbanization is ever increasing, balanced environmental and economic objectives need to be delicately determined (Zhuhadar *et al.*, 2017). Such planning would further facilitate the development of the land market; protect land and cultural resources (Keijer and Rietveld, 2000; May, 2015; Kummitha and Crutzen, 2017). Appropriate urban land-use decisions are critical determinants of environmental quality (Tyler and Spoolman, 2015). While other areas such as health, climate change and other economic policies and strategies are key features of this accepted wisdom; sustainable transportation infrastructures are also crucial items (Byrne *et al.*, 2004).

Conventionally, sustainable transportation infrastructure (STI) can be described as environmental, social and economic indicators with the possibility of addition of a separate and fourth aspect. Further, the nature of Transportation Infrastructure Projects (TIP) entails a prevailing STI to deal with uncertainties and predicaments. In addition, Ponti *et al.* (2013) noted that, sustainable uncertainties and predicaments such as unpredictable or unforeseeable situations can be defined as unconventional problems particularly for TIP. For example, important problems such as external social shocks, environmental uncertainties, significant engineering challenges and tentative fiscal future directions, make the achievement of sustainable outcomes even more complicated (Andres *et al.*, 2016; Cao and Orrù, 2014).

1.1 Purpose of this research

The objective of this paper is to initially evaluate the most current and important complications of sustainable mega rail transportation projects. This purpose is assisted by thoroughly reviewing the foremost uncertainties and challenging issues of STI. Once these factors are established, they will be the base of STI indicators. Finally, to consolidate such alignment, the Sydney Metro and Melbourne Metro are then compared and analyzed. The analysis would then create a platform to measure sustainability and relevant complexities in mega rail transportation projects.

1.2 Originality of this research

While the sustainability for transportation infrastructure has been covered extensively by other authors, this paper strengthens the four specific and separate STI indicators – especially for mega rail infrastructure. Although, there are some crossover areas within these indicators, however, this research separately validates each as an independent entity. Commonly, there are three dimensions within the sustainability domain – environmental, economical and social. Nevertheless, for this research a fourth-dimension engineering which includes all the technical focus, has been separately developed. This is particularly important to effectively deal with all the complexities, particularly for mega projects, such as rail transportation infrastructure. Accordingly, separating the engineering dimension would thus reshape the triple bottom line factors to include a separate technical focus. To further evaluate this separation of the four specific areas, two mega Australian rail transportation projects are then reviewed as experiments.

2. Literature review

More generally, transportation infrastructure consists of assets such roads, bridges, tunnels, rail systems and so on. Such assets are intended to be maintained for a long time by the continuing replacement and refurbishment of their components (Griškevičiūtė-Gečienė and Burinskienė, 2012). Likewise, the community has an expectation that infrastructure should also provide the service it was designed for over the life of the asset, leading to the concept of asset performance being incorporated into the triple bottom line of sustainability. Although the triple bottom line of sustainability includes the integration of environmental, economical and social factors, however, as already noted, this research proposes a fourth dimension of infrastructure that relates to the specific technicalities. The existing literature considers such fourth dimension to be included as a part of the other three. Incidentally, as a part of the mega rail transportation projects, the fourth dimension needs to be included separately, thus highlighting the complexities of such alignment. This four-dimensional alignment is shown in Figure 1.

The mega rail transportation infrastructure is different to the traditional projects. Due to their area of coverage, with some networks spreading well beyond 50 km, there are many uncertainties, predicaments and therefore immense complexities and probable risks. To further lessen such difficulties, the inclusion of fourth dimension will be beneficial. As the fourth dimension – engineering absolutely focuses on the technical demand of the infrastructure; the uncertainties and predicaments of the mega rail transportation infrastructure can be better understood and therefore the probable risks can be effectively managed. Figure 1 demonstrates the inclusion of the fourth dimension – infrastructure. While Figure 1 represents the overview of infrastructure performance during the planning stage for such assets, sustainability considerations include the comprehensive analysis to solve various transportation concerns (Gharehbaghi *et al.*, 2019). Accordingly, STI needs to consider a range of impacts in transport policy, planning and operations of such issues.

Conventionally, the environmental considerations are fundamental concerns of STI (Gharehbaghi and Sagoo, 2016; Carroll and Turpin, 2009). As a result, a detailed assessment needs to be carefully undertaken to ensure the ecosystem is vigilantly protected. For rail transportation infrastructure, this can be achieved via understanding the variability in urban environmental problems, including various sustainability issues and factors.

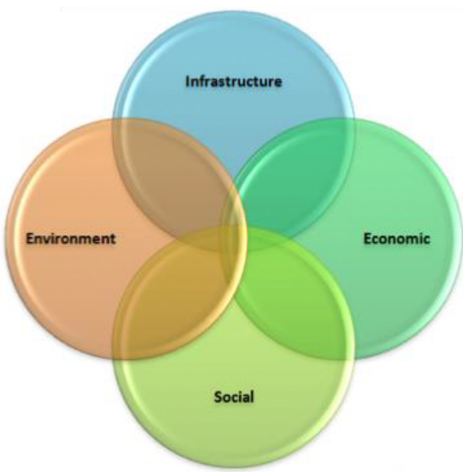

Figure 1. Overview infrastructure performance

However, to fully design and implement a sustainable transportation infrastructure, such as a rail project, its uncertainties and predicaments needs to be fully considered (Krasemann, 2015; Malavasi *et al.*, 2014). Closely investigating such dilemmas are necessary to further refine the sustainability of mega rail transportation projects. To support such hypothesis, He *et al.* (2016) also highlighted that, remedies and antidotes of such issues are not researched or developed exhaustively. To understand such concerns for the rail projects, STI and their overall capacities need to be carefully examined (Grilo *et al.*, 2015; Zeng *et al.*, 2007).

2.1 The overall capacity of sustainable transportation infrastructure

Whilst capacity generally refers to capability characteristics, the STI capacity, on the other hand, relates to both transportation design and use (Gharehbaghi and McManus, 2019). Traditionally, sustainable transport capacity can be defined in a number of ways and in particular, the required service provided with minimum environment impact (Scheepmaker and Goverde, 2015). This methodology also includes other factors such as cost, time, quality, life cycle and the provision of consistent service level over the project life (Cui *et al.*, 2016). This approach also covers the utilization of detailed infrastructure life-cycle processes (Elliott, 2014; Chung and Shalaby, 2005). The suitability of transportation infrastructure is further determined by their practicality (feasible and useful), together with their global environmental implications (Young, 2016; Schmidt *et al.*, 2008; Thomas, 1998; Valli Manickam, 2011). In addition, while the main benefit of adequate transportation infrastructure is to reduce traffic congestion, a more important social benefit would be to improve livability. While livability can be defined as adequate living conditions, the important aims of STI are generally based on environmental, economical and social improvements, predominantly in the light of uncertainty. Such sustainability is thus measured via direct and circuitous factors that, while improving the livability, would ultimately reduce life cycle cost, minimize ecosystem disruption and so on, through appropriate environmental impact evaluation (Glasson *et al.*, 2012; Kummitha and Crutzen, 2017).

Incidentally, the main environmental impacts of transportation infrastructure include the greenhouse emissions production during their construction and life-cycle phases (Tromans, 2012; Faiza *et al.*, 2016). Accordingly, deciding the most appropriate sustainable transportation infrastructures are fundamental undertakings. Further, Ghosh and Lee (2012) contend, the overall capacity and ability of the transportation infrastructure is situated within its constituents and include increased livability for the communities. Sladkowski and Pamula (2015) challenged this outlook and consequently recommended that such a standpoint needs to be more holistically created.

Subsequently, a holistic capacity of STI specifically for rail transportation, include the following assessment and measurements:

- ITCA. An Integrated Technical Configuration and Assessment (ITCA) in particular, the inclusion of local transport plans involving congestion modeling, together with appropriate accessibility and transport system representations (Gharehbaghi and Georgy, 2015). Accordingly, an integrated transportation system thus needs to be designed to include highway and road capacity schemes and management, public transport requirements, jointly with various freight, rail and metro redevelopment.
- AEMMM. An Accurate and particular Environmental Measurement, Mapping and Modeling (AEMMM) highlighting physical and ecological constraints and demands. Such environmental methodology includes assessments of alternatives, and impact on biodiversity, such as fauna and flora, soil, water, air quality together with the contemplation of climate factors and landscape character (Adli *et al.*, 2019).

- SIC. Social Implications and Considerations (SIC). Such deliberations need to include social impacts and equities, including community severance and so on (Tschirner *et al.*, 2014). In particular, the concept of social sustainability comprising public participation, education and governance also needs to be carefully investigated.
- ECOI. Economic Issues (ECOI), taking into account their inclusive cost drivers that will impact the overall design and cost of such the projects. Such construction drivers include, location and site variables, construction layouts, specific and specialized structures, required services and provisions, and so on (Cui *et al.*, 2016).
- LIM. Impact of policies and strategies with the support of Land Information Management (LIM). LIM is a dynamic system and assists with various project assessments (Garci-Mira *et al.*, 2005). In particular, incorporating the impact of policies and strategies such as Environmental Impact Assessment (EIA), this instrument provides a comprehensive evaluation capability. Moreover, LIM also assists with the evaluation of the long and short-term results of various policies and strategies. LIM can further estimate and validate the impact of policies and strategies in the context of environmental, economical and social inspirations on STI, holistically. LIM allows the responsible authorities, local stakeholders and governments to have an improved awareness of how to design and plan for future growth.
- Asset Performance. One of the most difficult technical aspects of STI includes the performance and capacity determination (Nicholson *et al.*, 2015). While such asset performance assessment deals with specific KPI's including appropriate efficiency rate, capacity on the other hand comprises the inclusion of desired functionality.

The overview of the STI indicators is presented in Figure 2.

Appropriately, the STI includes and successfully addresses the engineering, environmental, social and economic indicators of such projects. While the engineering indicator includes the technical configuration factor such as design schematics, it also consists of the ecological and physical structures of the transportation projects.

The environmental indicator includes both the ecological and physical structures. Likewise, the social indicator of the STI encompasses the actual economic structures as a main factor. Finally, the economic indicator also includes both the physical and economic structures as the basis of sustainable transportation infrastructure.

Incidentally, the STI also includes a number of sub-factors as the basis of its indicators. Such sub-factors are community tolerance, political administration and institutional response. All three sub-factors are therefore individually aligned with the STI indicators. In addition, for simplicity, these four STI indicators could be further dissected into main factors and main sub-factors. Where the main factors are those which have 'direct influence', the main sub-factors are aspects which have 'remote effect'. These main factors and sub-factors are shown in Table I.

Appropriately, to further analyze the main factors and sub-factors of STI, Figures 3 and 4 are presented.

As it can be seen, the main factors and sub-factors are categorized individually. While the technical configurations include specific design schematics, the ecological physical and economic structures, are the actual arrangements and compositions of such factors.

The main sub-factors consist of community tolerance and acceptance, political administration and management along with the institution's response. Owing to various governance commitments; the institutional response – that is analyzing, understanding and

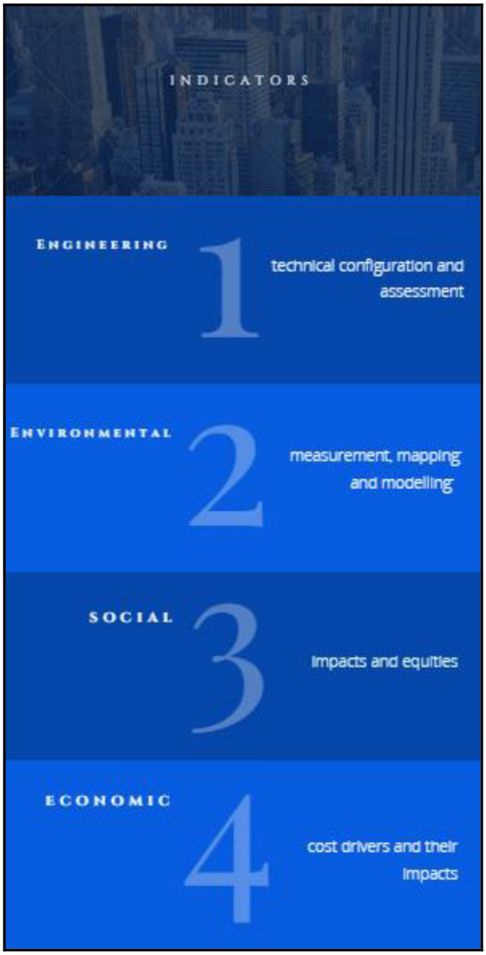

Figure 2.
Overview of the STI indicators

responding to diverse project situations, is the most important sub-factor. This is due to institutional ability to further refine the sustainability aspects of transportation infrastructure. Importantly, these STI indicators can be closely aligned with that of rail project's constraints. Both Tschirner *et al.* (2014) and Nicholson *et al.* (2015) alluded to such recommendations. Therefore, the STI developed in this research will be basis of comparing the Melbourne Metro Rail and Sydney Metro.

3. Research methodology

In general, the duration of the data gathering was approximately ten months, followed by an additional six months for the analysis of the results. Overall, this research involved a comprehensive methodology, which is illustrated in Figure 5.

This research uses sustainable transportation theory as the conceptual framework, together with qualitative development. In addition to a comprehensive literature

Factors	Level of influence	Explanation and rationalization
Technical configuration	*Main factors*	Sturdy design, mounting and integrations of Bridges, via ducts, tunnels and so on. Structural erection of Gantries, Catenaries, Sub-stations and Shelters. Maintenance intervals and processes, along with integration of high-performance Technologies to further improve the safety and increase the reliability of performance of the Transportation systems
Ecological structure		To further validate and protect the viability of natural and biological organisms
Physical structure		This relates to both the actual structure and its subsequent protection and prolonging life. Such strategies also includes considering the adjacent and surrounding area and environment
Economic structure		The inclusion of both short and long-term fiscal considerations
Community tolerance	*Main sub-factors*	The involvement of the community in the planning and initiations phases
Political administration		The inclusion of all level of government, including local, state and federal governance
Institutional response		The addition of comprehensive urban management strategies (this is discussed in detail later)

Table I. Main factors and sub-factors of STI

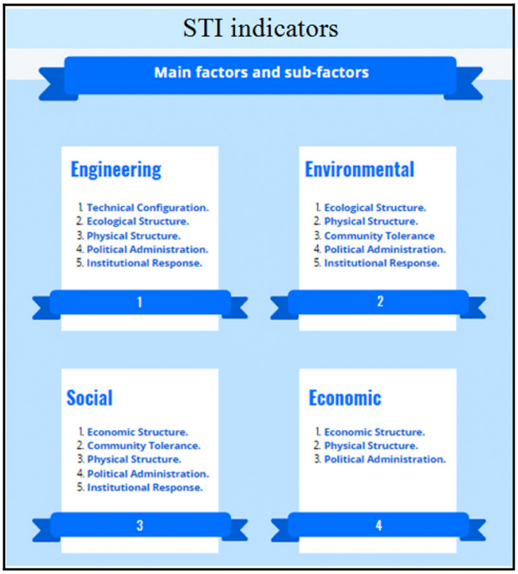

Figure 3. Main factors and sub-factors of the STI indicators

examination, the research methodology consisted of evaluating the STI of both Melbourne Rail and Sydney Metro projects. The raw data was gathered from site visits, log-books, various project reports, plans, design schematics, feasibility and preliminary reports. These were carefully assessed and scrutinized to further summarize the data. The next phase then consisted of comparing these two projects by means of appropriate empirical analysis. Such analysis, involved a careful assessment of the four sustainability indicators for each project.

Then, these four sustainability indicators were compared and consequently scrutinized (more information is provided in the following section). The subsequent findings of the research were then comprehensively examined. Through this descriptive and comparative method, the dynamic findings were then established.

4. Experimental studies: Melbourne Metro Rail and Sydney Metro

Rail transportation is generally a publicly owned network of infrastructure assets that have local, state and federal significance. Although, the actual operation and management of such assets may be conducted by the private sector, the actual asset ownership remains in the public domain. Therefore, the tangible construction, operation and maintenance of such networks is a functional liaison of non-profit, government bodies and contracted profit-making private authorities. Rail transportation projects are at times among the most complex and challenging ventures. Such multifaceted and demanding endeavors require careful planning as a part of their sustainability analysis (Vezzoli and Manzini, 2001). Such sustainability analysis is further complicated by the project's size and affected region.

To further simplify these uncertainties and predicament, this research proposes a fourth indicator - engineering, to separately cover the technical specifics of mega rail transportation projects. To evaluate such supposition, two mega rail transportation projects, Sydney Metro and Melbourne Metro Rail will be reviewed. These two Australian projects were selected as the basis of case study since both possess similar sustainability aspects and consequently similar STI indicators. Subsequently, their overall STI comparison provides a better understanding of complexities in mega rail transportation projects.

More importantly, the assessments in this section were based on both project's feasibility and planning reports. As a result, both project's indicators and their comparisons were

	Main Factors				Main Sub-Factors		
Indicators	Technical Configuration	Ecological Structure	Physical Structure	Economic Structure	Community Tolerance	Political Administration	Institutional Response
Engineering	■	■	■	-	-	■	■
Environmental	-	■	■	-	■	■	■
Social	-	-	-	■	■	■	■
Economic	-	-	■	■	-	■	-

Figure 4.
STI indicators and their influence

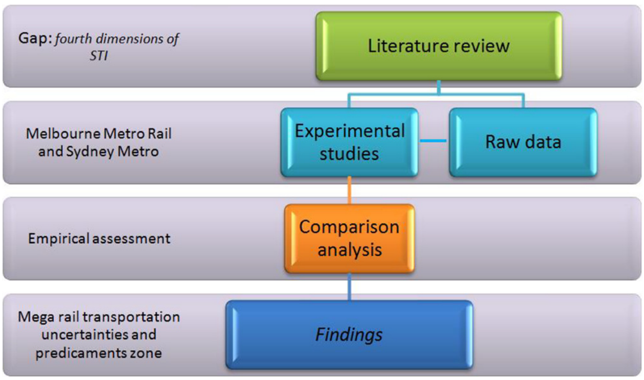

Figure 5.
Overview of the research methodology

further assisted by these two comprehensive reports. For each project, their specific influences and subsequent impacts were first identified and then, evaluated based on both short and long-term effects. In addition, specific rubrics (Figures 7 and 9) were then developed. The rankings of the influences ie, moderate, are based on "adequacy of each indicators". Another words, the overall relevance, influence and effect of each indicator. Subsequently, this ranking represents how each indicator influences its main factor, as well as its sub-factors.

4.1 Melbourne Metro Rail

According to MetroTunnel (2018), the Melbourne Metro Rail project is a mega metropolitan rail project presently under construction in Melbourne, Victoria. This project consists of the creation of a twin rail tunnel to pass through from South Kensington station to South Yarra (both within close vicinity of Melbourne CBD). The Melbourne Metro Rail project (Metro Tunnel) which is planned to open in 2025 consists of five additional underground stations connected via two 9 km rail tunnels. The general aim of this project is to bypass some of Melbourne's busiest stations and thus improve overall travelling times together with transporting approximately 39,000 passengers daily (during peak times). The Melbourne Metro Rail project will provide the ability to run multiple lines independently. In addition to facilitating high speed signaling, it would also significantly improve the existing capacity of Melbourne's rail network. The areas and subsequent regions of the Melbourne Metro Rail are shown in Figure 6.

The Melbourne Metro Rail covers a small to medium area. Due to its intermediate size, only the Melbourne City Council and related rail authorities are involved. These authorities include both private and public stakeholders. In addition, due to its underground nature, the environmental effects were very small (some ground water were encountered) and accordingly no major ecological problems were encountered. This project's STI indicators together with its main factors and sub-factors are presented in Figure 7.

It can be seen from Figure 7; the Melbourne Metro Rail project possesses a Marginal (minor) level of influence for both the factors and sub-factors. Although there are few Moderate (medium) influences, the average of the indicators for the Melbourne Metro Rail project is marginal. The level of influence was determined based on the critical factors that

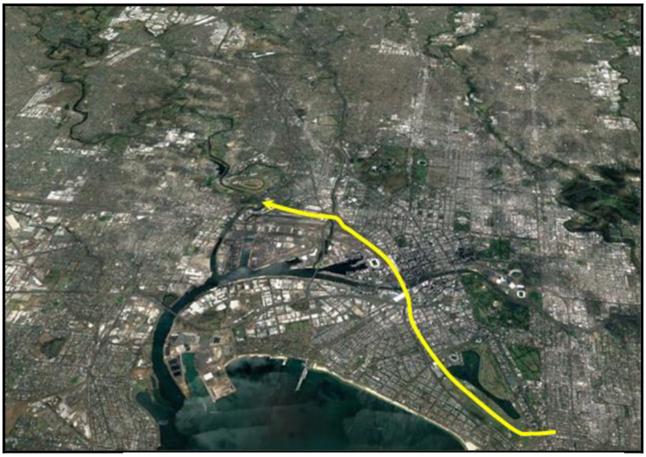

Figure 6.
Aerial mapping of the Melbourne Metro Rail

can affect the Melbourne Metro rail's success or failure. These critical factors were clearly highlighted in both the feasibility and planning reports for this project. Accordingly, such critical factors were assessed specifically within each indicator to further highlight their influence and subsequent impact.

Nonetheless, the moderate influences consist of technical configuration due to difficulties with the underground construction beneath the city. In addition, such technical challenges also created difficulties within institution response, in particular, not being able to select the most cost-effective transportation options due to the possibility of increased risk.

4.2 Sydney Metro

As Gharehbaghi and Sagoo (2016) reported:

> *The Sydney Metro is Australia's largest public transport project, costing over eleven billion (Australian dollars) with a contract period of seven years. This mega infrastructure project is a new stand-alone railway network, and consists of more than sixty-five km of metro rail from Rouse Hill to Bankstown, connecting the east and the west of the greater Sydney; via northwest and southwest sub-projects.*

The lines and subsequent areas of the Sydney Metro is shown in Figure 8.

The Sydney Metro covers a large and diverse spatial dimension of environmental zones and aims to provide a capacity of approximately 40,000 passengers during the peak times. This mega rail project is planned via two stages. Stage 1 (Sydney Metro Northwest) consists

	Factors (main)				Sub-Factors (main)		
Indicators	Technical Configuration	Ecological Structure	Physical Structure	Economic Structure	Community Tolerance	Political Administration	Institutional Response
Engineering				-	-		
Environmental	-			-			
Social	-	-	-				
Economic	-	-			-		-

KEY Moderate Marginal

Figure 7.
Melbourne Metro Rail STI indicators and their influence

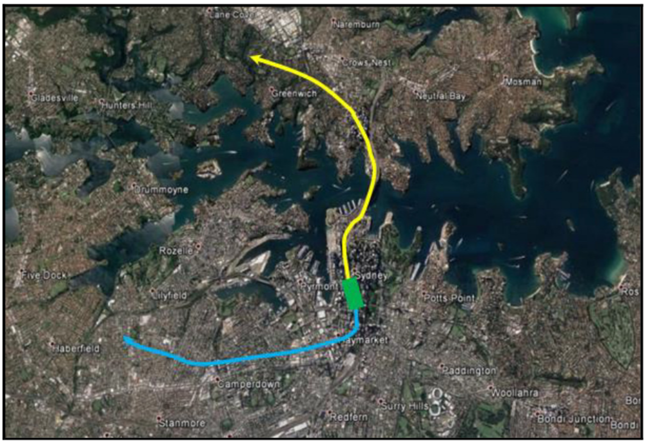

Figure 8.
Aerial mapping of the Sydney Metro: Stages 1 (yellow) and 2 (blue)

of 23 km connecting Rouse Hill to Chatswood and Stage 2 (Sydney Metro City and Southwest) entails 30 km linking-up Chatswood to Bankstown. Due to the size of the Sydney Metro, the roles of local actors and authorities became important. The impact on the Greater Sydney's environment was determined largely by the interaction of numerous public, private and household actors who had an important effect on ecological problems and their solutions. This project's STI indicators together with its main factors and sub-factors are presented in Figure 9.

As it can be seen from Figure 9, the Sydney Metro project mainly possesses Marginal (minor) level of influence for both the factors and sub-factors. Although there are some Moderate (medium) influences, the average of indicators for the Sydney Metro project is marginal, although at heightened levels. As per the Melbourne Metro Rail project, these critical factors were once again highlighted in both the feasibility and planning reports for this project. Equally, when differentiating between the two rail projects, the Sydney metro seems to possess a higher level of risk associated with its indicators, although none were critical or catastrophic. This assessment thus requires most scrupulous analysis to determine the reasoning for such finding (discussed in Section 6). Once again, the level of influence was determined based on the critical factors that can affect the Sydney Metro's success or failure. Once more, such critical factors were assessed specifically within each indicator to further highlight their influence and subsequent impact.

5. Comparison analysis: Melbourne Metro Rail and Sydney Metro

As a part of the case studies analysis, specific data collection and extraction phases were involved. First, the values calculated in this section are based on the four indicators of, engineering, environmental social and economic. This arrangement made the analysis process more streamlined and thus less uncomplicated. This process involved summarizing of each STI indicators and their influences, subsequent analysis and findings specifically into four sustainability indicators. Second, for impartiality purposes, these four indicators are thus treated the same for (comparison's) influence.

5.1 Empirical analysis: outcome and discussion

Incidentally, it is important to note that the Melbourne Metro Rail is significantly smaller in scope compared to the Sydney metro. However, to further analyze these two projects and observe their comparison, the four sustainability indicators were carefully examined and determined. The four sustainability indicators were scrutinized via the following scenarios:

(1) Engineering: any issues in the terms of design, construction, maintenance and outline complexities.

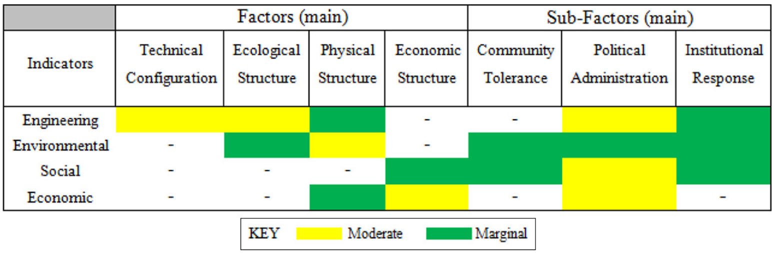

Figure 9.
Sydney Metro STI indicators and their influence

(2) Environmental: such as climate (temperature, rainfall, wind etc.); energy (light, noise, vibration and so on); and Flora and Fauna (birds, mammal, terrestrial vegetation etc.).
(3) Social: including demography (population structure and trends and so on); and local issues (services, health education etc.).
(4) Economic: any concerns in terms of direct issues (labor market, local and non-local trends and so on); and indirect issues (non-basic services, long-term fiscal issues, etc.).

As the basis of empirical analysis, each of STI indicators and their influences were specifically grouped into four sustainability dimensions. To further demonstrate such comparison and process, the following values were then given – 1: for Low impact, 2: for Intermediate and, 3: for High influences. The rational for the inclusion of such values was based on the indicators impacts - that is, the level of relevance, influence and effect. Table II provides the overall comparison of Melbourne Metro Rail and Sydney Metro sustainability indicators.

Table II provides the overall comparison of the four sustainability indicators for both rail projects. As noticed, the overall sustainability value of the Sydney Metro is seemingly higher than the Melbourne Metro Rail. This is due to higher environmental, economic and social indicators. Thus, overall the Sydney Metro has higher sustainability implications. This is due to Sydney Metro's greater size resulting in more complex and compound issues. Although the Melbourne Metro Rail project also possesses technical complexities, the Sydney Metro's scientific issues are more extreme. For such reason, the other remaining two indicators are also moderately elevated.

The comparison of both mega rail projects indicates sophisticated sustainability challenges. This in turn will set up a number of challenging uncertainties and predicaments. Table III represents the key sustainability uncertainties and predicaments of both rail projects.

Table III provides the key sustainability uncertainties and predicaments of both rail projects. As previously discussed, such issues include unpredictable or unforeseeable situations. Although, the internal reports for both rail projects determined that some engineering uncertainties are probable, appropriate measures were undertaken to safeguard against such issues. In addition, the said internal reports for both rail projects, also highlighted that while wireless technologies are not new and have been used globally, their use for these projects required more careful consideration. Accordingly, technicality issues such as, choosing the right technology, mobility limitations and autonomous vehicles were all comprehensively studied and deliberated. As a part of STI consideration, these projects also carefully considered innovative material selection for structural elements, different composite substance and so on. Such STI considerations created various engineering and environmental predicaments. On the one hand, both rail projects possessed complicated social factors. Further, the economic uncertainties and predicaments for both mega projects also limited the appropriate financial forecasting. Finally, for both rail projects, it was determined that protecting and enhancing the environmental health such as shielding water, soil and air quality was paramount.

Overall, although the sustainability uncertainties and predicaments of both rail projects are time consuming, however, they are manageable. This requires a holistic STI approach, particularly appropriate institutional integration. The institutional integration requires the incorporation of all the relevant authorities such as VicRoads, Transport for NSW, Melbourne Metro Rail Authority, Environmental Protection Authority (EPA) and so on. Such institutional integration further enhances the sustainability aspects of both mega rail transportation infrastructure.

Table II. Comparison of Melbourne Metro Rail and Sydney Metro (overall) sustainability indicators and implications

Transportation projects	Engineering	Environmental	Social	Economic	Overall sustainability value
Melbourne Metro Rail	Low Soil and Geology issues	Low Climate impact	Low Demography issues such as lack of trust from effected shop owners	Intermediate Direct issues	15
	High Design complexities	Intermediate Energy usage Low Flora and Fauna affect	Intermediate Local issues	Intermediate Indirect issues	
Sydney Metro	Intermediate Soil and Geology issues	Intermediate Climate impact. Intense strategies to reduce carbon footprints	High Demography issues, such as relocation of some residents and locals	High Direct issue s, such as very complex and compound Profits/ Losses statements	28
	High Design complexities	Intermediate Energy usage issues during the construction	Intermediate Local issues such as rezoning some neighborhoods	High Indirect issues including too much legal interface	
	Intermediate wireless communication and data capacities issues Low issues with utilization of experimental recycled materials, including composites	High Flora and Fauna affect		Intermediate Productivity and Growth issues	

Transportation projects	Engineering	Environmental	Social	Economic
Melbourne Metro Rail	Lack of suitable terminologies and inconsistencies with how technical uncertainties meant to be deal with	Uncertainty in environmental impact assessment predictions, thus the need for better communication and more transparency	Complicated policy context, and institutional capacity	Unclear financial vulnerabilities
	Lack of detailed evaluating dynamic and reliability measures			Broad implementation of future economic activities
Sydney Metro	Lack of defense-in-depth strategies	Lack of short term strategic orientation	Blurred mega data and the analyses associated with it	Compound performance indicators
	Numerous technical haziness, imprecision and instabilities	Complex EIA scientific assessments		Undecided auditing considerations and processes
	Convoluted theories in how advancing Technologies to meet			

Table III.
Key sustainability uncertainties and predicaments for both rail projects

6. Research findings

This research demonstrated that as a part of STI in mega rail projects, important matters which require careful attention when considering sustainability are, the significance of uncertainties and predicaments in dealing with such projects. For both Melbourne Metro Rail development and Sydney Metro projects, such problems were associated with-in areas where all the four-dimensional alignments overlap. The reason for such inclusion was the overlapping STI confusions and uncertainties. The overlapping uncertainties and predicaments of both projects are shown in Figure 10.

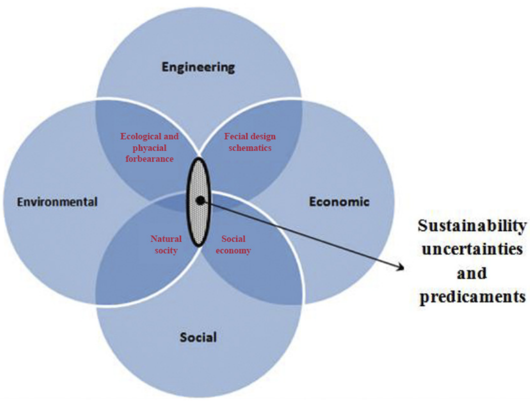

Figure 10.
Melbourne Metro Rail development and Sydney Metro uncertainties and predicaments zone

Figure 10 considers the traditional economic, environmental and social aspects that are part of any sustainable development. The inclusion of the new dimension of "Engineering (Technicality)" as the basis of the fourth pillar of STI is necessary for the mega and complex ventures such as those found in rail projects. This inclusion is therefore unique as a part of the STI. Also as shown in the preceding diagram, the STI uncertainties and predicaments in mega rail projects are positioned within the overlapping area.

For both Melbourne Metro Rail development and Sydney Metro projects, the existence of such a predicament was based on future STI challenges and opportunities including:

- imperfect equalization or not balancing all the four sustainability indicators; and
- where and how to emphasize the overlapping of these four indicators.

For that reason, such a dilemma created certain uncertainties and predicaments. Such uncertainties and predicaments across all four areas included:

(1) not replicating the same antidotes;
(2) receiving the appropriate and equal level of commitment across all areas;
(3) un-clear and unbiased institutional responses from all levels of governments; and
(4) ensuring that the relevant authorities and establishments are not locked out from each area.

The new findings clearly highlighted the complexities in mega rail transportation projects through the integration of STI and more importantly dissipating the uncertainties and predicaments zone. However, with the inclusion of the fourth dimension – engineering, such difficulties can be further minimized. Such outcome is the center-piece of this research, and therefore streamlines the treatments to aforementioned uncertainties and predicaments.

7. Conclusion

Generally, the nature of mega rail transportation infrastructure projects thus entails a systematic sustainability focus. The mega rail transportation infrastructure are different to the traditional projects. Due to their area of coverage, there are many uncertainties, predicaments and therefore immense complexities. To further lessen such difficulties, the inclusion of fourth dimension – engineering was developed in this research. As shown in this paper, as the fourth dimension – engineering focuses on the technical demands of the rail transportation, the uncertainties and predicaments of such infrastructure can be better recognized and therefore efficiently managed. To further vindicate such hypothesis, this research investigated two mega rail transportation projects Sydney Metro and Melbourne Metro Rail. Their overall sustainability comparison provides a better understanding of complexities in mega rail transportation projects.

Further, the empirical analysis of these two mega rail transportation infrastructures emphasized that, complexities in such projects are less predictable and based on many sustainability uncertainties and predicaments. Although such issues are complex to deal with, they are manageable due to involvements of all the relevant authorities from the conception phases through to the finalization stage of both rail projects. Importantly, the success of the Sydney Metro and Melbourne Metro Rail projects is the result of on-going and positive collaboration between all the relevant establishments. Such collaboration is the epitome of meeting sustainable rail infrastructure complexities and complications. Finally, the findings discussed in this research can be developed into framework to address the interweaving complexities in mega rail transportation projects. This can then assist the rail transportation planners and researchers to further refine the sustainable transportation.

Subsequently, this can lead to creation of improved strategies to better plan for mega rail transportation projects.

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