A Feasibility Study into the use of String Transport Systems for Passenger Rail in New South Wales

Aaron James Hargraves

Supervisor – Dr. Upali Vandebona

ABSTRACT

String Transport Systems (STS) are an efficient rail technology currently under development in Russia by String Technologies Unitsky. This technology utilises high-tension steel cables within concrete filler, in place of conventional steel rails.

To determine the feasibility of STS application, a technical analysis and design has been carried out in this paper, particularly in relation to; application site selection, demand estimation, structural design, and costing. Based on this information, the best use for this novel technology was found to be a route from Sydney's Kingsford-Smith Airport to Bondi Beach, which has been designed and developed. The structural and geotechnical elements of this route were designed using Australian Standards, and compared with data available from String Technologies Unitsky.

This design found that the route had the capacity of carrying the current estimated demand of 12,300 passengers per day between Sydney's Kingsford-Smith Airport and Bondi Beach, with provisions to increase this number to 80,000 in the future. The travel time was 25 minutes on this 20.42 km route, which is less than current public transport options, as well as personal rapid transit. Structurally, the typical supports and foundations of a STS network were compliant with Australian Standards, ensuring a satisfactory design. The string-rail, the novel component within this technology, also sufficed design loading and when life cycle costing was considered, STS offered savings of 75% when considering its counterparts.

From the analysis of the transport elements, and structural and geotechnical design of the structure, STS has been proved feasible for small scale implementation in highly urbanised NSW areas. Based on this conclusion, further research towards implementation should now be possible.

INTRODUCTION

Problem statement

Background to the study

The New South Wales' passenger rail network is expansive, extending to the majority of New South Wales, with thousands of kilometres of track. There are currently light rail and heavy rail services in use, with most of Sydney's suburbs having rail transit options.

Sydney's urban rail network is suffering from excessive patronage putting a large demand on the network. This has resulted in the network reaching capacity in many locations, and with high levels of urbanisation, network extensions are both costly and technically difficult.

Areas such as Sydney's Eastern suburbs do not have a rail network and have required residents to utilise lengthy bus journeys to reach the city. This and other current methods of dealing with these rail network problems have been inferior, with the problems reaching breaking point before the Government has acted in many cases. Light rail extensions have been suggested to get around urbanising issues, as well as costly tunnelling works, however they are either slow or costly options.

With these meagre attempts at addressing the problems facing the current Sydney rail network, an appropriate solution is yet to be found. Until such a technology is found, and is implemented, these 'Band-Aid' approach solutions will have to suffice.

String Transport Systems, a developing Russian technology, uses high-tension steel cables within a concrete filler on an elevated structure, in place of conventional steel rails. A typical cross section is presented in Figure 4 and from design and testing, it appears to be able to operate and satisfy the requirements and needs specified above.

The feasibility of implementing an alternate technology, String Transport Systems in this case, is therefore the topic of this investigation.

Objectives
To conclude on this feasibility of implementing an alternate rail technology for use in passenger rail in New South Wales, the following objectives have been set for completion in this paper:

- Conduct research into the technology, String Transport Systems, and the associated performance measures;
- determine the need for an alternate technology, and the best application for it;
- develop a route or a network for the technology including the estimated demand on the network;
- ensure the structural integrity of the rail technology under operation to Australian Standards;
- determine the financial feasibility of introducing the technology to the New South Wales Passenger Rail Network; and
- determine the feasibility of implementing this technology based on all of the above information.

With these objectives achieved, a realistic conclusion will be made on the implementation of an alternate transport system.

LITERATURE REVIEW

String Transport Systems are a unique approach to passenger transportation that combine the concepts of high tensioned steel cables with railway. This technology has been under development in Russia by Dr. Anatoly Yunitskiy since 1977 and is still in development with no active railway of its kind currently built in the world. All that exists is a 1.5 km test model built in 2001, as well as several scaled models of 1:2, 1:5, 1:10 size (Yunitskiy, 2010). A variety of patents and inventions are linked to String Transport Systems. In August of 2010 Yunitskiy published a detailed technical paper on the applications of String Transport Systems technology for use in iron ore transport within Australia (String Transport Systems Limitied, 2010). This will form a platform for the technical design aspects in this paper. Multiple suggestions have also been made for possible routes in Tasmania, Adelaide, Gold Coast, Sydney, and interstate predominantly published by Yunitskiy's Transnet company (Yunitskiy, 2013d). These applications as well as the countless papers based on Russian networks will form the basis of the review of the literature associated with the feasibility of the use of String Transport Systems for passenger rail in New South Wales. Where gaps exist, relevant resources will be used in an attempt to fill the gaps for a holistic feasibility study.

Key Vendors

String Technologies Unitsky (STU) is the overarching company responsible for String Transport Systems directed by Dr. Anatoly Yunitskiy. The technology platform, STU has grown from a variety of research developments, representing all of Yunitskiy's innovative technologies and infrastructure including String Technologies Unitsky (STU), String Transport Systems (STS), Unitsky String Transport (UST), Transport Systems Yunitskiy (TSY), and Yunitskiy String Transport (YST), all directed by Anatoly Yunitskiy (Yunitksiy, 2013a).

The company operates in Russia and is responsible for all technology and developments. This includes development in the rail, automotive and aviation industry. Three subsidiaries are operated in Australia. String Technologies Unitsky Pty Ltd is the freight based application of the technology whilst String Transport Systems Pty Ltd is the passenger based application. The company Transnet, also owned by Dr. Anatoly Yunitskiy, operated in both Russia and Australia. This company has a slightly different focus than String Technologies Unitsky Pty Ltd and String Transport Systems Pty Ltd, with a focus on a global transportation network. Yunitskiy is quoted as "Internet — global information network, which helps the transition of humanity to a new level in the 20th century. Transnet — global transportation network that will provide a transition to humanity to the next quality level of development in the 21st century." (Transnet, 2012a). The goal of this company is to provide an international network, with sub networks within each continent littered with infrastructure including hotels along the network.

Due to the large number of companies set up by Yunitskiy, with such large varieties of applications, the commercial viability of the technology is very prevalent. Each company carries out a variety of different tests and research projects helping to promote the technology towards implementation.

Key innovations

The company String Transport Unitsky has registered more than 50 Russian and Eurasian patents over the past 20 years (Transnet, 2012b). The technology, including the patents had an estimated value of 1-14 Billion USD in 2010 (Yunitskiy, 2010). This is a considerable amount of money for a technology which is yet to be implemented into an operational railway. Yunitskiy himself has invested 100 million USD into this technology,

Others have also suggested that this is cutting edge and innovative technology. When presented to the President of Russia, Dmitry Medvedev in 2009 he was quoted as saying; "150 years ago, when it was told about a locomotive, experts in the field of horse traffic were smiling too, like some kind of nonsense talk. But then it became a whole industry which, by the way, is leaded by you". (Yunitskiy, 2009). This indication from the Russian President shows that this technology, although not currently implemented, is innovative, and some may find it unfeasible, but it could be a future form of Transport, led by String Technologies Unitsky.

String Transport System Usage

String Rail

Yunitskiy has published numerous reports on the specifications of his technology. Whilst a large amount of this information is confidential, hence the value in his companies, these publications do provide the specifications of the both the networks and the rolling stock. This will form the basis of the below details on the specifications of String Transport Systems.

A detailed analysis and independent calculations of String Transport Systems is carried out on page 9 of this paper predominantly drawing from information provided in the previously mentioned report on iron ore transport in Australia (String Transport Systems Limitied, 2010). Due to the detailed nature and applicability of this data, where gaps in Yunitskiy's data exist, current railway and structural design practice have been used to determine results and vice versa.

Uses in Passenger Rail

Inter-urban railway within New South Wales is currently run by New South Wales TrainLink (previously Countrylink). There are four main services; the North Coast Train Services, North Western Train Services, Western Train Services and the Southern Train Services.

As the current network is already well developed, the String Transport System rolling stock would have to be retrofit for operation on the current network. However, costs are lower and train speed is higher so recovery of the cost of redesigning rolling stock has the potential to be rapid. New South Wales would then be moving towards a potential technology of the future, again, as mentioned by Russian President Dmitry Medvedev (Yunitskiy, 2009).

This application of String Transport Systems differs from what Yunitskiy had originally dreamed for his technology, with the hallmark of his work, the string-rail. Only utilising his rolling sock in a retrofit manner is not an appropriate way to consider the implementation of String Transport Systems when many other alternatives do exist.

The Melbourne-Sydney-Brisbane High-Speed Rail Network has been looked at for some time now. In 2011 AECOM headlined a consortium of consultants on the 'Phase 1 High Speed Rail Study' for the Department of Infrastructure and Transport to provide an insight into when the design would likely be feasible and where to progress design to. The report suggests that by 2036, the project would have a Positive Net Present Value (NPV) and should be considered (AECOM Australia Pty Ltd, 2011).

This application has significant potential for String Transport Systems as construction costs are lower and hence the design is feasible earlier based on NPV. The trip from Albury to Sydney currently takes 6 hours and 38 minutes (Tourisminternet, 2013). At a distance of 553 km, this trip would take under 2 hours on the high-speed string network as well as a similar time for the proposed high-speed rail. The difference; Yunitskiy noted in his paper, Unitsky String Technologies - Overground Transport System, was that the land acquisition for elevated string technology is only 2.5% that of conventional rail, 1.6% of automotive transport and 40% that of monorail. (Transnet, 2012b). With the phase 2 report released in April 2013 and the land acquisition data available, the saving in land acquisition costs could then be estimated. The study indicated that land acquisition costs are 3.4 % of the total cost which is estimated at $114 Billion in 2012. This is almost 4 billion dollars in land acquisition (AECOM Australia Pty Ltd, 2013). With String Transport Systems requiring only 2.5% the land acquisition of conventional railway, the savings are over 3.5 billion AUD. This example clearly shows a feasibly application for String Transports Systems use in passenger rail in New South Wales.

Sydney's transport network, specifically the rail network, is severely overcrowded. Capacity has already been met in many locations and drastic measures are already underway to fix the problem. Two current projects under study/design are the light rail project to Randwick, and the recently approved 1 million AUD study on tram lines connecting Parramatta with Castle Hill and Macquarie Park.

These technologies are under investigation due to the highly urbanized areas within Sydney. Suggestions were even made to tunnel a section of the CBD on the South East Light Rail Project due to the inability to find an appropriate or wide enough corridor. With the option for fixed or elevated string transport structures, String Transport Systems are more than suitable. The previously mentioned paper on freight based application of String Transport Systems outlines that supports for the structure are as little as 200 mm diameter pipes (String Transport Systems Limitied, 2010) whilst something like the Sydney monorail has support beams which are over 600mm in width. This clearly shows how String Transport Systems are the superior design option for this use, when minimising the physical footprint is an issue.

With such a small physical footprint characterising String Transport Systems, uses in urban rail is another possible application for their use in passenger rail in New South Wales.

String Transport Systems within Alternate Transport Systems

Rail transit can be broken into a variety of categories. These categories distinguish the different methods of rail transit and their uses. The main categories include, but are not limited to; light rail, high-speed rail, personal rapid transit, conventional rail and alternative/sustainable transport solutions.

String Transport Systems have been in development for a number of years and the design has progressed from a concept, through to a proven full-scale test with freight and passenger implications. Due to the environmental and sustainable benefits associated with this technology, it fits into the overarching group of alternative/sustainable transport solutions.

Integration

Integration with the current New South Wales network is necessary for successful implementation of String Transport Systems for passenger rail. Due to this, information provided in this literature review will be used to form a basis for the String Transport System application decision, to ensure the best usage of this technology is selected for Passenger Rail in New South Wales.

Conclusion

It is conclusive from the literature reviewed that the state of New South Wales is in need of a technology to enhance its current network. The rural rail network is suffering from an ailing fleet of rolling stock in need of replacement and some of New South Wales' major cities such as Sydney are clogged with infrastructure, with networks approaching capacity. Feasibility studies are underway to install a high speed interstate route, however the state is in need of an alternative to provide mass transit within the city.

The technology, although not in implementation anywhere in the world, has been developed and from thorough research of many of Yunitskiy's research papers, is demonstrated to be able to be implemented effectively in New South Wales. This paper will ultimately represent this.

METHODOLOGY

The desired outcome of this paper was to assess the feasibility of use of String Transport Systems for passenger rail in New South Wales.

A detailed analysis of current literature on both the technology being considered, as well as the New South Wales passenger rail network has been conducted and is outlined on page 4. This outlines current String Transport System best practices as well as the applications for it within passenger rail in New South Wales. This literature review also explores the current states of New South Wales passenger rail network and the implication this has on String Transport Systems.

A String Transport System route was then produced to demonstrate the travel time capabilities of the technology. Detailed curve and alignment design was undertaken, producing maximum curve speed data, and ultimately, a route travel time. This data, coupled with demand estimation was then used to produce a timetable. Information in regard to rolling stock (rolling stock refers to locomotives, carriages, wagons, and other vehicles used on a railway (Oxford Dictionaries, 2013)) and its subsequent interaction with the rail has not been found for this investigation, however the rolling stock is assumed to behave in a similar manner to that of conventional rolling stock (String Transport Unitksy, 2006).

The demand estimation was based on Australian Bureau of Statistic population data, combined with current public transport information in the area of interest. This allowed an approximate value for the demand to be found and was deemed to be satisfactory for a feasibility level of design. Detailed demand estimation would be required before a final route could be installed. Demand estimation is an inherently error prone process however, as shown by many of Sydney's tollways, hence the assumption to use approximation methods, holds.

From the route produced, a typical support structure was designed structurally and geotechnically to Australian Standards. The most unfavourable loading conditions were applied to this structure, which was designed in the worst soil conditions that would be expected along the route in order to assess the impact, in worst case conditions. Key strength and serviceability values were calculated to determine the factor of safety that the structure was designed to when designed to Australian Standards. Where dynamic information was required, Yunitskiy specified information was used, as no dynamic analysis or testing was undertaken.

The cost of construction of the route was carried out based on all of the above information. The costing aimed to produce a value per kilometre, which could be compared to typical values per kilometre of other forms of rail transit. Involved in this costing were; labour, materials, traffic works, site management, design, commissioning, land acquisition, rolling stock, stations and a depot as well as a contingency value due to the inherently high level approach taken to a feasibility level design. Other rail projects around New South Wales, and in some cases, Australia were averaged to produce their costs for a comparison. When considering lower operational costs of String Transport Systems, the saving produced by this technology was outstanding.

All of the information presented above was then used together to conclude on the holistic feasibility of implementing this technology in New South Wales for use in passenger rail.

SELECTION OF APPLICATION SCENARIOS FOR ANALYSIS

When considering String Transport Systems for use in passenger rail, the literature review has ruled out use in rural rail. The two options that remain are urban rail and high speed rail.

When considering urban rail, Sydney's urban rail network will be considered. This network is currently at capacity in many locations and due to high levels of urbanisation, many locations are not currently reachable by rail. A current network extension in to Sydney's Hills District, North West Rail Link, requires 15 km of tunnel to reach its desired destinations (Transport for New South Wales, 2013a). Sydney's Eastern suburbs are also without a rail network due to high levels of urbanization, with plans to introduce a light rail network to help the public transport congestion in the area.

String Transport Systems are characterised by elevated structures and when considering the high levels of urbanisation are perfectly suited for such applications. Structures are spaced between 10 and 25 metres in the design to follow, so the physical footprint will be small enough to not effect heavily urbanised areas.

The current urban rail network is very established although there are limited opportunities for further expansion in urban areas. String Transport Systems provide an alternative to allow for expansion into these areas, however due to compatibility between String Transport Systems and the current network, String Transport Systems would be required to be a stand-alone network with transport interchanges to effectively integrate it into the Sydney public transport scheme.

Given the clear demand for a new technology to be used in urban rail, such as String Transport Systems, high speed rail will therefore be ignored. There is a market for high speed rail in Australia, however given its current negative net present value, it should be ignored.

When considering the above information it is clear that the most compatible and appropriate use for String Transport Systems would be in the form of a stand-alone route or network in a highly urbanised area where conventional rail is unable to be built, or was not a cost effective option. This recommendation will form the basis for completion of the following chapters.

ROUTE DESIGN PROCESS

The design of the network in this case is an 'out and back' route rather than a network, with a terminus at each end. The route connects the suburbs of Bondi, Bondi Junction, Randwick, Coogee, Maroubra Beach, Maroubra Junction, and Eastgardens with the Sydney Airport.

Large patronage and small headways would result in large numbers of passengers at each station. This is what formed the basis of the station locations, with one in each of the previously mentioned suburbs. These stations are located at current Sydney Bus terminuses or major bus stops. Each of these is also located at a demand centre, such as the Eastgardens station being located at Westfield Eastgardens.

From the route below in Figure 1, it can be seen that the route has longer flowing curves in most areas allowing for high-speed transport and simpler acceleration/deceleration patterns. With minimal stops compared to a bus route, the route travel time between terminuses will be far less than that of normal buses.

Connecting Sydney airport and Bondi junction is the 400 bus route (effective September 2013). This route takes 45 minutes in minimal traffic (NSW Government, 2013), with an approximate time to reach Bondi Beach being one hour.
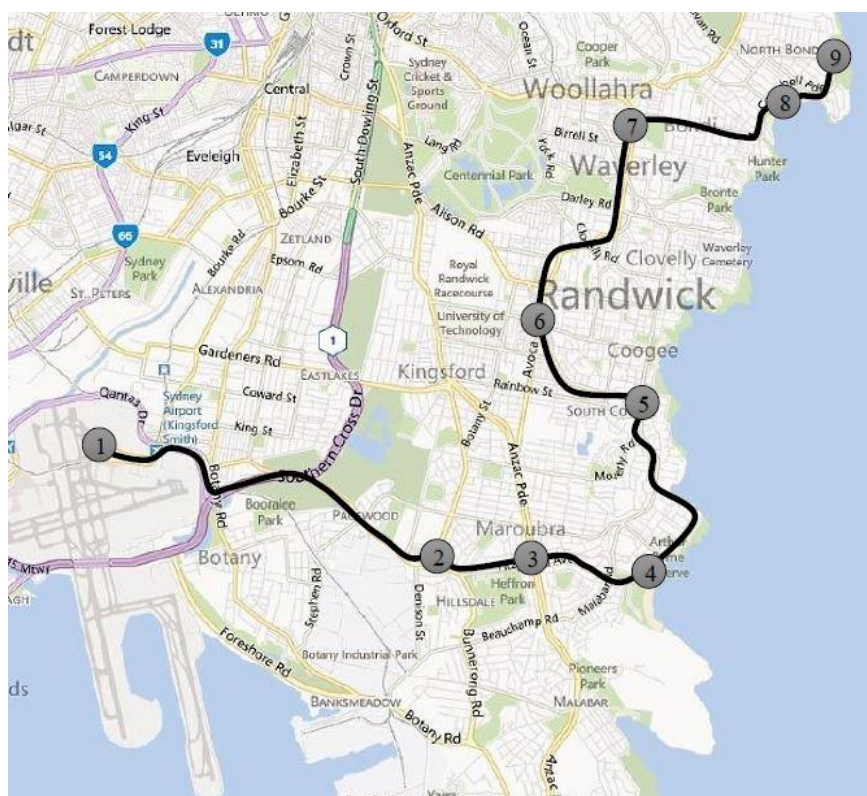
The horizontal alignment of the route presented in Figure 1 consists of 22 curves ranging in radii from 250 metres to 2 kilometres, as well as 10 straight sections. The high usage of curves as opposed to straight section, although difficult to construct, has been used for the aesthetical applications, to mimic the rolling curves of the Sydney coastline. The route does however aim to travel down the centreline, specifically the median strip, of major roads due to the negligible land acquisitions that this will require.

The following maximum velocities presented in Table 1 have been calculated for the given curve radii

Figure 1: Proposed Route between Kingsford-Smith Airport and Bondi Beach

Table 1: Maximum Curve Velocity

Curve Radius (m)	2200	1000	750	650	500	350	250	Straight Section
Maximum Velocity (ms^{-1})	28.00	28.00	24.00	22.00	19.00	16.00	14.00	28.00

To determine the approximate demand for the above route, the current airport rail and bus services will be considered along with Australian Bureau of Statistic population information. The Eastern suburbs population, as a percentage of Sydney's total population will be applied to the current hourly services from the airport for an approximation of the demand.

There are currently 131 train services from the airport to central between the hours of 4.56 AM and 0.54 AM (AirportLink, 2013). These services are 8 carriage sets and are capable of carrying 1000 passengers each (Sydney Trains, 2013). There are also 54 bus services to Sydney's eastern suburbs each day on the 400 bus route (Sydney Buses, 2013b) between 5.29 AM and 11.58 PM, each with a capacity of 58 passengers (Sydney Buses, 2013a).

Australian Bureau of statistics data was used to estimate the population of Sydney's eastern suburbs and in turn, this as a percentage of Sydney's total population. Population statistics were however only provided for council areas, so each council which falls within the route designed will be included. The population of Sydney's Eastern Suburbs turned out to be 6.4% of Sydney's total population with 306,950 residents (Australian Bureau of Statistics, 2012). To determine the number of services per hour using String Transport Systems, the current services were kept at the same ratio of services per hour, however with only 6.4% of the patronage when compared to current capacity.

With this demand in mind, it was decided to use 5 carriage sets when using a Yunitskiy specified rolling stock with carriages of 20 capacity. This gave each train having a capacity of 100. This results in a maximum of 8 trains being required per hour, during the peak patronage of the day between 5 and 7 pm. The maximum allowable services per hour, calculated based on travel times and appropriate headways, was calculated to be 10 services per hour, fitting within the demand calculated.

Based on this information, a suggested weekday timetable is able to be produced. There are a total of 123 services per day, capable of carrying 12,300 passengers. The timetable suffices the demand estimation carried out with a 4 hour shut down period of a night for scheduled maintenance similar to Sydney Train procedures.

Route summary

Given the decision to design a route in an urban New South Wales environment, an effective route has been developed from Kingsford-Smith Airport to Bondi Beach. The journey has been calculated to only take 25 minutes, characterised by higher speeds than what is conventionally able to be experienced by light rail vehicles and personal vehicles. This is what Yunitskiy has specified as one of the key advantages of such a technology. Table 2 below compares the travel times experienced by a personal vehicle (Google, 2013) and current public transport options (NSW Government, 2013) with String Transport Systems to reach each station location from Sydney's Kingsford-Smith Airport. As clearly shown, the travel time on a String Transport System route, is far superior in travel time than current public transport options. The route also outperforms a personal vehicle to all locations, excluding the North Bondi Terminus.

Table 2: Travel Time Comparison

Station	Personal Vehicle (Mins)	2013 Public Transport (Mins)	String Transport Systems (Mins)
Eastgardens	11:00	24:00	3:58
Maroubra Junction	13:00	26:00	6:28
Maroubra Beach	17:00	36:00	8:56
Coogee Beach	18:00	36:00	12:42
Randwick	16:00	34:00	15:31
Bondi Junction	20:00	28:00	19:15
Bondi Beach	23:00	42:00	22:08
North Bondi Terminus	24:00	45:00	24:17

With higher speeds, 123 services can be offered per day to satisfy estimated demand of up to 12,300 passengers per day. This allows passengers to connect with `major transportation interchanges within Sydney's eastern suburbs, connecting to over 80 bus routes.

This route, the best application of String Transport Systems, not only services large volumes of passengers, but also helps to fill the rail void within Sydney's Eastern suburbs.

DESIGN OF STRUCTURE

The loads that will be applied to the structure for design, are the standard loads considered in conventional railways design to provide consistency when comparing String Transport Systems to conventional forms of railway.

Calculation and detailed analysis of dynamic forces are out of scope of this paper and are subject to further investigation. Where gaps exist, information has been taken from String Technologies Unitsky reports, or basic calculations have been performed.

Due to the small size of the structure, and the large vertical and horizontal loads experienced, the effects of wind are ignored. It is assumed they are negligible on a structure of this size and this design strength. Numerous wind-tunnel tests however, have been carried out by String Technologies Unitsky at the Krylov Central Scientific Research Institute in St. Petersburg Russia on 1:5 scaled models. The testing showed that a train travelling at 250 km/hr with a 200 km/hr side wind would not break its wheel-rail contact and derail. (String Transport Unitksy, 2006). Given the highest wind gust ever recorded on mainland New South Wales was 174 km/hr (Bureau of Meteorology, 2013), the above assumption is deemed satisfactory.

Foundation

Basic foundation design methods will be used to design a foundation for a typical support structure. Key considerations include the effect of the foundation under load, foundation type as well as the expected soil properties in Sydney's Eastern suburbs.

The Australia standard on piles is AS 2159-2009: Piling - design and installation (Standards Australia, 2009c). This standard dictates that loading be factored based on AS1170.1. The standard also dictates that steel piles be designed to AS4100, with an allowance made for corrosion of the pile.
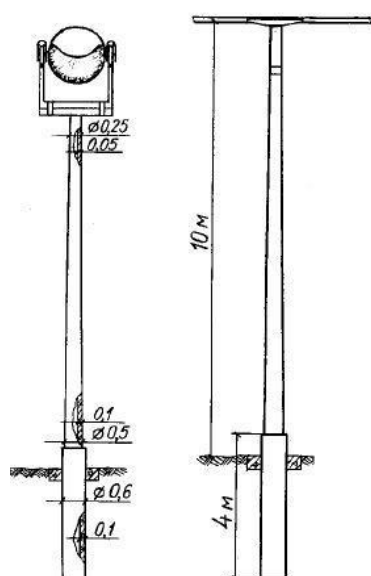
Anatoly Yunitskiy has dictated in his preliminary design work that the foundation should be 4 metres in length and include a diameter of 600mm with a thickness of 10mm. (Yunitskiy, 2010). Figure 2 below shows these geometric properties suggested for a typical support including foundation.

This design however, will include both tracks supported on the one column. Therefore the structure in Figure 3 will be used (pile not shown). This structure will again use a monopole design, but has a 1.0 metre diameter base and a length of 7 metres.

Various types of foundations that can be used for design. This preliminary design will be done in medium density Sydney sand, as sand is the most common material found in the region of interest (Sydney Environmental and Soil Laboratory, 2007). Medium density sand is also quite weak, and hence a design will be deemed conservative if it is satisfactory for medium density sand.

Figure 2: Suggested Foundation and Support - Geometric Properties (Yunitskiy, 2000)

Typical Sydney medium density sand was found through triaxial testing to have a cohesion co-efficient of 0 and an angle of friction of 41.42°

(Hargraves, 2011). This test was carried out under drained and undrained conditions using mohr-columb failure envelope analysis. Other useful values for medium density sand, using driven piles are $Ktan\delta$=1.0 and Nq=100 (Taiebat, 2012).

The loads applied to the pile were found and are presented in Table 3 below. The capacities and there factory of safety is also presented in Table 4

Table 3: Pile Loads

Load	Value
P*	390.286 kN
M*	721.020 kN.m
H*	270.020 kN

Table 4: Pile Capacities

Capacity	Required	Value	Factor of Safety
Axial Capacity	$P^* \le \phi_g P_u$	$\phi_g P_u$ =2,256.29 $kN.m$	5.78
Lateral Capacity	$H* \le H_u$	H_u=348.291 $kN.m$	1.29

Support

The design of the supports is based on the most unfavourable loading conditions the supports will be exposed to. The design is constructed of steel so design will be carried out to Australian Standard 4100 – Steel Structures (Standards Australia, 1998).

There are two types of supports used in String Transport Systems design. The first is used every kilometre and is what the string is tensioned between. These are what will be referred to as a tensioning support. The second type is an intermediate support, spaced every 10-25 metres used to eliminate the effect of sag on the structure.
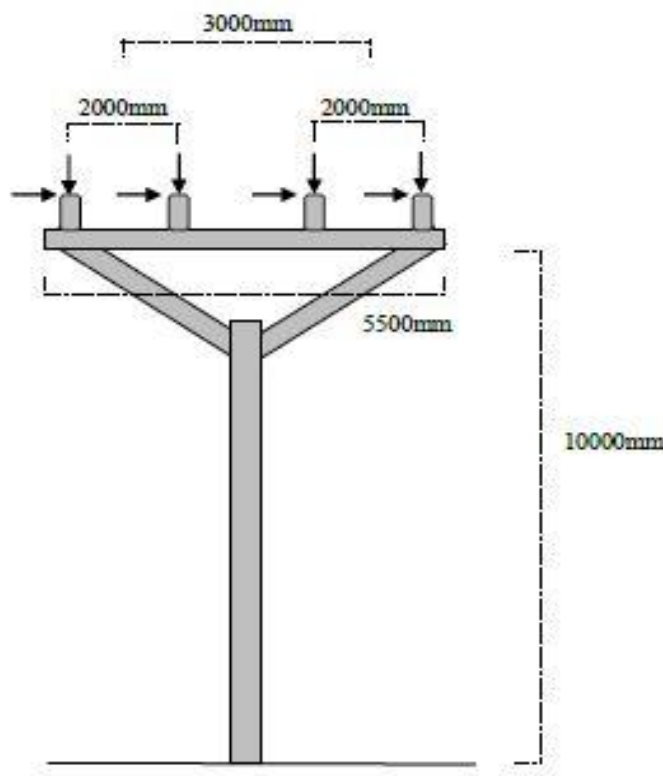

Figure 3: Typical Support Structure

A singular support has been designed, and will be of the intermediate support design, ignoring the 'tensioning block' that would be required in a tensioning support. As the tensioning would occur in both directions on such a support, there would be no net horizontal force, the only requirement would be the capacity of the block. There would however be second order effects on the support from rolling stock moving past, but this dynamic analysis is subject to further investigation. The typical support will be assumed to be satisfactory in such supports, however there will be the inclusion of the tensioning block. The structure will act somewhat like a cable stay bridge in this instance.

The structure is presented to the left. The following beam design capacities and factor of safeties were found and are presented in Table 5: Beam Design Capacities

Table 5: Beam Design Capacities

Capacity	Required	Value	FOS
Section Capacity	$M_x{}^* \leq \phi M_{sx}$	ϕM_{sx}=1,101.643 $kN.m$	4.75
Bending Capacity	$M_x{}^* \leq \phi M_{bx}$	ϕM_{bx}=776.483 $kN.m$	3.35
Web Shear Capacity	$V* \leq \phi V_v$	ΦV_v=1,102.702 kN	5.96
Bending and Shear Interaction	$V^* \leq \phi V_{vm}$	ΦV_{vm}=1,102.702 kN	5.96
Bearing Capacity	$R* \leq \phi R_b$	ΦR_b=605.797 kN	3.28

The following column design capacities and factor of safeties were found and are presented in Table 6: Column Design Capacities

Table 6: Column Design Capacities

Capacity	Required	Design	FOS
Section Capacity for Member Exposed to Combined Actions			
Compression	$N^* \leq \Phi N_s$	ΦN_s=6,237 kN	15.98
Uniaxial Bending about x-axis	$M^* \leq \Phi M_{rx}$	ΦM_{rx}=900.630 $kN.m$	1.25
Uniaxial Bending about y-axis	$M^* \leq \Phi M_{ry}$	ΦM_{ry}=900.630 $kN.m$	6.36
Biaxial Bending Capacity	$(M_x{}^*\Phi M_{rx}+M_y{}^*\Phi M_{ry}+N*\Phi N_s) \leq 1$	$(M_x*\Phi M_{rx}+M_y*\Phi M_{ry}+N*\Phi N_s)$=0.905	-
Member Capacity for Member Exposed to Combined Actions			
Compression	$N^* \leq \phi N_c$	ϕN_c=6,052.149 kN	15.51
In-Plane capacity about x-axis	$M^* \leq \phi M_{ix}$	ϕM_{ix}=891.910 $kN.m$	1.24
In-Plane capacity about y-axis	$M^* \leq \phi M_{iy}$	ϕM_{iy}=891.910 $kN.m$	6.30
Out of Plane Capacity	$M_x{}^* \leq \phi M_{ox}$	ΦM_{ox}=940.273 $kN.m$	1.30
Biaxial Bending	$((M_x*\Phi M_{cx})^{1.4}+(M_y*\Phi M_{iy})^{1.4}) \leq 1$	$((M_x*\Phi M_{cx})^{1.4}+(M_y*\Phi M_{iy})^{1.4}) \leq 0.754$	-

String Rails

As mentioned in the introduction, the string-rails are what makes String Transport Systems so unique. This is the defining characteristic, which differs from conventional rail. This chapter presents the design of the string-rails including the benefits and the constraints of the technology.
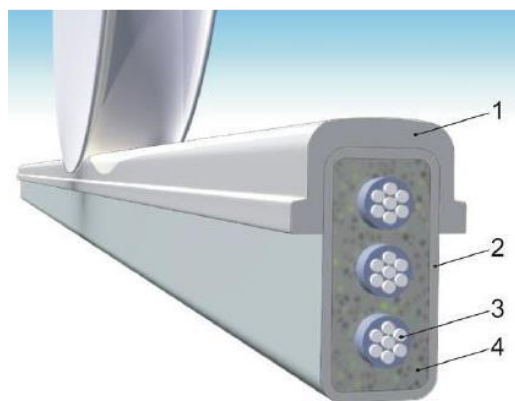
What Characterises String-Rail?

Figure 4: String-Rail Cross Section (Yunitskiy 2006)

String-rail consists of 3 highly tensed steel cables inside a concrete 'filler' with a steel rail head on top. These strings are tensioned at 1 kilometre intervals (String Transport Unitksy, 2006), so must be supported along the way with use of intermittent supports. A typical string-rail cross section is shown below in Figure 4.

The steel cables within the string-rail are tensioned at 1 km intervals, each string-rail is tensioned to a total of 250 tonnes (250,000 kg-force) (String Transport Unitksy, 2006). Each string is made up of 3 steel cables. Each will subsequently be tensioned up to a force of 83333.33 kg-force (816.67 kN).

The string are suggested to be 35mm in diameter, but to design to AS 4672.1:2007 - Steel prestressing materials, Part 1: General Requirements (Standards Austrahla/Standards New Zealand, 2007), 36 mm strings will be used.

Using 7 string strands, with each of these being 11.1 mm strands, a diameter of 36 mm can be achieved with the use of filler;

$minimum\ breaking\ force$ = $7*138kN$ = $966\ kN$

The loading on the string in a vertical direction consists of rolling stock and self-weight. Each of these will be considered as a uniform distributed load. Again each load has been factored as per Australian Standard 1170 requirements (Standards Australia, 2009b). $Rollingstock$ = $1.5*1.717$=$2.575\ kN/m\ per\ string\ String$ ($Concrete$) = $1.35*0.638$ =$0.861\ kN/m$

$String$ ($Steel\ strand$) = $1.35*0.040$ = $0.054\ kN$/m

The amount of deflection caused by 'sag' in the string is found based on methods of calculation used in HV electric cable calculations, as the string-rail closely mimics the behaviour of such HV wires. The calculation of such sag, only includes the associated steel uniform distributed load, the concrete within the steel rail will be added to deflection calculations later as a dead load.

$Mid\ Span\ Sag$ (S)= $WL^2/8T$=$3.98\ mm$

W=$0.054\ kN/m$

L=$25\ m$

T=$816.667\ kN$

This is deemed a satisfactory deflection for design as this produces a maximum vertical acceleration of 0.138ms-2. This is slightly above standard railway best practise, with a Part 2 Design and Costing suggested limit of 0.1ms2 (Parsons Brinckerhoff Quade & Douglas, inc. , 1999). To ensure a comfortable ride for passengers travelling along the route, the rolling stock would require to be dampened, or the string tension reassessed.

Design Summary

Based on the most unfavourable loading conditions, the typical support structure was found to be satisfactory when designed to Australian Standards by a factor of safety of between 1.25 and 16. The largest sized standardly available UB and CHS were used, however should design loading increase for any reason, or should

the factor of safety be deemed not acceptable, the design can utilise welded beams and welded columns, a stronger alternative.

The foundation also proved to be satisfactory at a feasibility level of design also satisfying by a factor of safety of between 1.3 and 6. This design was only carried out for design in medium density sands, and further investigation is required in regard to the pile behaviour in other soil types such as clay.

The string also produced satisfactory performance measures when designed to Australian Standards, producing minimal mid-span deflections, resulting in a smooth and comfortable ride for rolling stock over the top. The steel cables when tensioned only satisfied by a small factor of safety in regard to breaking tension. Due to the extreme reliance on the string-rail, this may be deemed unacceptable. Designing with marine grade steel cable, instead of general purpose steel cable will increase the breaking tension of the cable, and subsequent factor of safety, eliminating this issue.

When compared to Yunitskiy's designed structures presented in several of his technical papers and in Figure 3, the structure and foundation designed here is slightly larger in size. This is due to the more conservative loadings taken in this design as well as the more conservative design methods used within Australian Standards when compared to Russian design standards.

COST ANALYSIS OF THE PROPOSED STRING TRANSPORT SYSTEM

Introduction

With any government project (ultimately what String Transport Systems will become in this application), one of the key factors on its implementation will be the cost. This chapter aims to breakdown the cost of constructing a String Transport System route, as well as exploring basic operational costs to provide a comparison with other forms of rail currently in use in New South Wales. Key costs considered include; materials, labour, rolling stock, infrastructure, rolling stock, design, commissioning, traffic management and contingency. These will be detailed in the following sub chapters. Where costs are based on information from the past, the Australian Bureau of Statics CPI inflation calculator has been used to convert the values to the equivalent June 2013 Australian Dollar (Australian Bureau of Statistics, 2013). Where costs are not in Australian dollars, they have been converted to Australian dollars at the point history where the costs have been specified with use of the Foreign Currency Exchange website's currency converter (Foreign Currency Exchange, 2013).

All costs below are considered to be conservative for the feasibility stage, and all values are taken at a maximum where multiple possible costs exist.

Cost of construction

The cost components of constructing a String Transport System network are summarised below in Table 7. The table summarises the total cost of construction of the route under consideration.

Table 7: STS Construction Cost

Item	Unit Price (AUD)	Number of Units	Total Cost (Million AUD)
610UB152	2,076.50	1,270 pieces	2.64
502CHS12.1	2,210.00	1,270 pieces	2.81
1000x7000 Pile	2,275.00	1,270 pieces	2.89
35mm Cable	49.00	245,142.86 metres	12.01
Concrete	100.75	2,215.57 m^3	0.22
Materials (Extra)	1,000.00	1,270 pieces	1.27

Construction Labour	4,000,000.00	20.43 km	81.71
Stations	133,506	7 pieces	0.93
Terminus	5,562,750.00	1.5 pieces	8.34
Traffic/Site Management Etc.	1,400,000.00	20.43 km	28.60
Design and Commissioning	148,543,444.58	9%	13.37
Land Acquisition	-	-	4.09
Total	**-**	**-**	**161.91**
Contingency	161,912,354.59	50%	80.96
Total including Contingency	**-**	**-**	**242.87**

Operation

To consider whole of life costs, to effectively represent the cost of implementing this system, the cost of operation needs to be considered. Detailed costing of such operation is subject to selection of rolling stock and subsequent interaction with the rail. Detailed costing of operation is out of scope and subject to further investigation, however String Technologies Unitsky have specified indicative costs, which will be used to compare with conventional rail to provide a comparison.

With the given demand estimation presented on page 7 and the price of diesel at $1.60 per litre (Australian Institute of Petroleum, 2013), the cost of fuel per year has been estimated for three modes of transport. This costs is presented in Table 8 below. The cost will have high volatility though as it is directly correlated with the price of diesel, however the cost ratio between modes will be the same.

Table 8: Fuel Cost Comparison

Mode of Transport	Fuel Required Per Year (Litres)	Cost of Fuel Per Year (AUD)
String Transport Systems	73,371.26	117,394.00
Conventional Rail	733,712.60	1,173,940.00
Passenger Vehicle	2,445,709.00	3,913,134.00

Cost conclusion

As it can be seen, the total cost for this 20.42 km out and back route is 242.87 million AUD. This equates to 11.89 million AUD per km of track. Figure 5 below presents typical values for conventional rail, light rail, monorail and personal rapid transit projects around the New South Wales and Greater Australia Region. Each price is again converted to 2013 AUD.
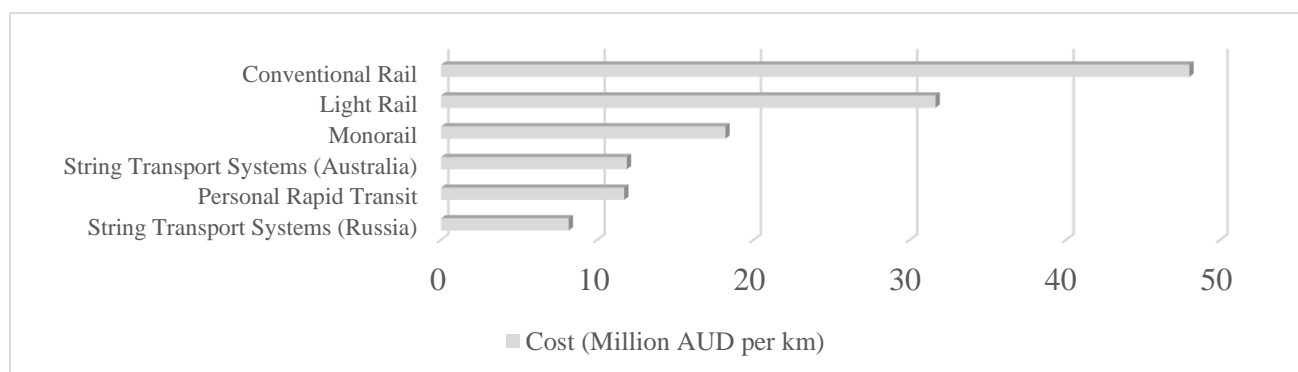

Figure 5: STS Construction Cost Comparison

As it can be seen, there are huge savings in using String Transport Systems. With conservative costing, and a large contingency value, the cost is still cheaper than all methods of transport excluding personal rapid transit. Personal Rapid Transit is however a very differing technology and in the circumstances of the above route, it would not be a feasible design due to the large land requirements.

Summary

The costs associated with string transport system construction for the selected route in eastern Sydney are far lower than other rail alternatives as presented in Figure 5. With smaller construction costs, also comes shorter construction times, allowing a project like this to be up and running earlier, achieving a positive NPV in a shorter period of time.

Yunitskiy specified his construction costs for a miniSTU network, the equivalent application to what is designed here to cost 8.17 million AUD per kilometre (String Transport Unitksy, 2006). The differences in cost between this, and the value of 11.89 million AUD per km shown in Table 7, are put down to a variety of reasons. For one, the structure is designed to Australian Standards, a more conservative standard, and is therefore larger than the one designed to Russian standards, resulting in an increased material cost. The cost of labour is also higher in Australia than in Russia. The route designed in this case is also made up of flowing curves through highly urbanised environments. When compared to straight track, in areas with minimal land acquisition costs, the costs can be seen to really blow out.

RECOMMENDATION/FEASIBILITY

The New South Wales' passenger rail network is in need of alternate technologies to assist in servicing areas of high urbanisation and reduced capacity public transport. In this paper, is it recommended that String Transport Systems be used as this alternative to conventional rail systems.

The methodology followed in this paper has provided an effective platform for concluding on the feasibility of implementing String Transport Systems for Passenger Rail in New South Wales. Analysis of needs before designing of the route allowed for the most appropriate route to be designed, and with the detailed information of this route, estimated costing could be undertaken. This coupled with skills in civil engineering and project management to undertake the feasibility study, have allowed for a report to be completed, similar to the style of that prepared in industry.

The proposed route for String Transport System application is from Sydney's Kingsford-Smith Airport to Bondi Beach. This decision is based on the current needs of New South Wales' passenger rail network when considering rural rail, high-speed rail and urban rail. The route has been designed to carry 12,300 passengers per day based on demand estimation with provisions to increase this to 80,000 passengers per day. These capabilities suggest that the route would satisfy Sydney's growing population into the future as well as the demand on Sydney's Eastern suburb's beaches during the summer months.

The 20.42 km route also has superior performance, reaching Bondi Beach in under 25 minutes, faster than other public transport options as well as personal travel. The route consists of 7 stations between two terminuses, with curves ranging in radius from 250m to 2,200m. These 7 stations connect public transport interchanges with the route, with stations spaced between 1.1 km and 4.8 km.

The typical support structure of the String Transport System, designed to Australian Standards was deemed to be satisfactory. A typical support utilised a 610UB152, 502CHS12.1 as well as 1000mm diameter piles, and was designed conservatively allowing these elements to be optimised for a more cost effective design. Although differences exist from the specification initially provided by Yunitskiy, and this proposed design to Australian Standards, the increased size of the structure can be attributed to conservative design and loading. Further dynamic analysis as well as testing in Australia could provide more efficient solutions in this case.

The cost analysis of the construction of 1km of String Transport System route was found to be 11.89 million AUD. This was a saving of over 75% when compared to conventional rail and 35-62% when compared with monorail and light rail. This independent analysis has produced a cost 40% higher than that specified by Yunitskiy. This discrepancy is again put down to conservative design, and the increased materials and labour cost in Australia when compared to Russia. In terms of operation, String Transport Systems also have savings when compared to conventional rail with 90% less fuel consumption per passenger and 70% less emissions. The potential financial benefits of using this technology, contribute to the decision of the feasibility of implementation of String Transport Systems for passenger rail within New South Wales.

Based on the need for an alternative form of technology within the Sydney urban rail network, as well as the associated demand, design of the structures and the costing of String Transport Systems, it is feasible for implementation. The performance in terms of travel time and demand servicing, is greater than current methods available and the financial and environmental benefits make this a more superior choice for an alternative rail technology.

It is concluded that further research can now be commenced on the design of a full scale route for implementation of this technology across a variety of rail applications within Australia.

REFERENCES

AECOM Australia Pty Ltd, 2011. *High Speed Rail Study - Phase 1,* Canberra: Department of Infrastructure and Transport.

AECOM Australia Pty Ltd, 2013. *High Speed Rail Study Phase 2 Report,* Canberra: Australia Government Department of Infrastructure and Transport.

AirportLink, 2013. *Airport to City - Weekdays.* [Online]
Available at: http://www.airportlink.com.au/time-table-to-city-weekdays.php
[Accessed 10 10 2013].

Australian Bureau of Statistics, 2012. *3128.0 Regional Population Growth, Australia,* Canberra: Australian Bureau of Statistics.

Australian Bureau of Statistics, 2013. *Consumer Price Index Inflation Calculator.* [Online]
Available at:
http://www.abs.gov.au/websitedbs/d3310114.nsf/home/consumer+price+index+inflation+calculator
[Accessed 10 10 2013].

Australian Institute of Petroleum, 2013. *Weekly Diesel Price Report.* [Online]
Available at:
http://www.aip.com.au/pricing/facts/Weekly_Diesel_Prices_Report.htm
[Accessed 20 10 2013].

Bureau of Meteorology, 2013. *Facts on Severe Wind Gusts in NSW.* [Online]
Available at:
http://www.bom.gov.au/nsw/sevwx/windfact.shtml
[Accessed 12 10 2013].

Foreign Currency Exchange, 2013. *Foreign Currency Exchange Rates and Currency Converter Calculator.* [Online]
Available at: http://www.fx-exchange.com/
[Accessed 10 10 2013].

Google, 2013. *Google Maps.* [Online]
Available at: maps.google.com.au
[Accessed 20 10 2013].

Grzesiakowski, T., 2013. *End of the Line for the Sydney Monorail.* [Online]
Available at: http://www.metroplanning.org/news-events/blog-post/6761
[Accessed 10 10 2013].

Hargraves, A., 2011. *CVEN2201 Soil Mechanics - Laboratory Test 5 - Triaxial Testing,* Sydney: University of New South Wales.

Jones, H. M., 2009. Personal Rapid Transit for Canberra. *Telecommunications Journal of Australia,* 59(1), p. 6.1 to 6.10.

New South Wales Parliament Legislative Council - General Purpose Standing Committee No. 33, 2012. *Rail Infrastructure Project Costing in New South Wales,* Sydney: New South Wales Parliament Legislative Council.

NSW Government, 2013. *TransportInfo - Plan Your Trip.* [Online]
Available at: www.131500.com.au
[Accessed 20 10 2013].

Oxford Dictionaries, 2013. *Definition of rolling stock in English.* [Online]
Available at:
http://www.oxforddictionaries.com/definition/english/rolling-

stock#m_en_gb0716410?view=aus
[Accessed 10 05 2013].

Parkz, 2010. *Sea World Monorail System.* [Online]
Available at:
http://www.parkz.com.au/parks/AU/Gold_Coast/Sea_World/ri
des/31-Sea_World_Monorail_System.html
[Accessed 05 10 2013].

Parsons Brinckerhoff Quade & Douglas, inc. , 1999. *Track
Design Handbook for,* Washington: Transportation Research
Board, National Research Council.

Parsons Brinckerhoff, 2009. *Hobart Light Rail Cost Estimate:
Desktop System Design and Service Model,* Brisbane:
Department of Infrastructure, Energy and.

Standards Australa/Standards New Zealand, 2007. *AS/NZS
4672.1:2007 - Steel Prestressing Materials, Part 1: General
Requirements,* Sydney: Standards Australia.

Standards Australia, 1998. *AS4100:1998 Steel Structures,*
Sydney: SAI Global Limited.

String Transport Systems Limitied, 2010. *Technical
Specifications of Freight String Transport System for Highly
Efficient Transportation of Bulk Commodities,* Sydney: s.n.

String Transport Unitksy, 2006. *String Transport Unitksy in
Questions and Answers,* Moscow: Anatoly Yunitskiy.

Sydney Buses, 2013a. *Chartering a Bus.* [Online]
Available at: http://www.sydneybuses.info/chartering-a-bus
[Accessed 15 09 2013].

Sydney Buses, 2013b. *Sydney Buses Timetable - Burwood to
Bondi Junction,* Sydney: Sydney Buses.

Sydney Trains, 2013. *Facts and stats.* [Online]
Available at:

http://www.sydneytrains.info/about/environment/
[Accessed 09 09 2013].

Taiebat, H. A., 2012. *Applied Geotechnics CVEN3201 - Student
Notes,* Sydney: University of New South Wales.

Tourisminternet, 2013. *Sydney to Albury.* [Online]
Available at: http://www.tourisminternet.com.au/howsyd.htm

Transnet, 2012a. *Transnet,* Moscow: Anatoly Yunitksiy.

Transnet, 2012b. *Unitsky String Technologies - Overground
Transport System,* Moscow: String Technologies Unitksy.

Transport for New South Wales, 2013a. *North West Rail Link.*
[Online]
Available at: http://northwestrail.com.au/
[Accessed 21 05 2013].

Yunitksiy, A., 2013a. *Summary of Technology, String
Technologies Unitksy,* Moscow: String Technologies Unitsky.

Yunitskiy, A., 2000. *TECHNICAL PROPOSAL - Ring High Speed
String, Transport Links [translated],* Moscow: String Transport
Unitsky.

Yunitskiy, A., 2009. *STU Presentation to Russian President
Dmitry Medvedev.* Ulyanovsk City(Ulyanovsk): Anatoly
Yunitskiy.

Yunitskiy, A., 2010. *The Biography of Dr. Anatoly Yunitskiy.*
[Online]
Available at:
http://www.yunitskiy.com/author/biography_en.pdf

Yunitskiy, A., 2013d. *Unitsky String Technologies - Section in
English.* [Online]
Available at: http://www.yunitskiy.com/author/english.htm

For a full copy of this paper, presented here in conference form, please contact hargravesa@pbworld.com