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EXECUTIVE SUMMARY

Engineers Without Borders (EWB) is a non-profit organisation working at a grass-roots level to implement practical and innovative engineering solutions to improve the quality of life underprivileged communities. The 2011 EWB challenge is a design program seeking to address the development issues faced by the rural community of Devikulam in Tamil Nadu, south-east India. Our team investigation considers the insufficiencies of the current transport system supporting Devikulam and surrounding communities which restrict access to resources and services, as well as educational and economic opportunities. Our aim is to develop a sustainable system (focusing on both transport mode and infrastructure) that will increase inter-village and rural-urban connectivity, the mobility of the Devikulam community and consequently their quality of life. The purpose of this report is to offer an integrated proposal which we believe can resolve a number of issues within the design area of transportation.

In keeping with the EWB Challenge, our team investigation considered not only communal requirements but also climatic and geographical restrictions as well as the socio-cultural context of the project. Devikulam is situated in a low-lying area and experiences a hot monsoonal climate that often leads to the flooding and erosion of poorly maintained regional transport infrastructure. Our design solution also had to maintain the cultural heritage of the community while working towards the dissolution of social barriers caused by the caste system operating in the region. In order to determine the most appropriate solution an evaluation criteria was developed against which the validity of proposals are measured according to their technological, social, environmental and economic implications. After consideration of possible
alternative transport solutions including public transport connections, renewable energy vehicles it was decided that a design solution based upon the concept of bicycle transport would be ideal for local requirements and constraints and in terms of the sustainability goals of the project. Our proposed solution, the Nadukuppam Sustainable Transport Program, aims to develop a concept design that provides Devikulam and surrounding communities with a more efficient, sustainable and equitable method of transport. To effect real and significant change in terms of local transportation, the scope of the project was extended to include neighbouring communities of the Nadukuppam Panchayat.

The project proposal will be implemented in a number of design stages, with the Cycleway Construction and Maintenance scheme being the principal element of the program. This initial stage of the project involves the provision of a cycle-way transport network servicing Devikulam and surrounding communities within the Panchayat. The cycle path will be integrated into the original road network; replacing, supplementing or extending existing routes regarded as fair or poor quality in order to minimise construction cost and environmental impact. Through a detailed whole of life analysis of the available unsealed gravel, concrete, chip seal and asphalt surface treatments, a 3m wide, 2-way path of unreinforced concrete was deemed the most appropriate option in terms of performance, cost, longevity and suitability to local conditions. While determining the ideal placement of the transport network would require extensive community consultation, supplementing the underperforming roads would require the construction of nearly 20km of concrete pathway at a combined cost of construction and maintenance of $2.23 million over its 40 year design life. While our team realizes this is a significant investment it was deemed necessary to provide a capital works program of this magnitude. The flow-on economic effect of increased access to services and trade markets for the communities within the Panchayat will make this scheme not
only sustainable but also financially viable. The success of this project relies critically upon the assumption of securing necessary funding, for which the Prime Minister’s Rural Roads Program is an ideal candidate. This is a joint development initiative between the World Bank and India’s Central Government, currently responsible for the maintenance and construction of 375,000km of Indian rural roads with similar project goals to our team requiring $40 billion of investment. Feasibility also relies upon the availability of local materials and the technical capacity of local construction companies to provide quality, lasting infrastructure.

Complementing this design stage is the Bicycle Provision Program that seeks to promote sustainable bicycle use as the predominant transport mode by providing equitable and economical access to residents. Bicycles will be supplied at a minimal cost to residents of Devikulam and surrounding communities through recovery from urban areas, charitable organisations and expansion of existing government programs. The Bicycle Sale, Maintenance and Retrofitting Centre serves the important purpose of ensuring the long term viability of the project, facilitating a regular bicycle maintenance schedule while becoming a local source of employment and entrepreneurial activity. This Centre will also cater for the needs of the community through the construction of rickshaws, pannier attachments and other requirements. The final design phase is the implementation of a sustainable transport education program. Operating in parallel with current Pitchandikulam Forest Environmental Education Programs, our program seeks to direct social perceptions towards the benefits of sustainable transport, securing local patronage of bicycle use for the long term through the communal acceptance of a ‘bike culture’.

This report presents an in-depth proposal that fulfills the transport needs of the Devikulam community while upholding the sustainability goals of the EWB challenge. As a consequence of extensive research into the key issues and contextual boundaries of the project,
as well as an intensive analysis of possible solutions, we believe that our final proposal represents the ideal solution for the design problem. If the capital investment necessary to support this project can be sourced our team supports the implementation of our proposal. However in light of the assumptions made in this report, to proceed beyond the design stage further client discussion would still be necessary in order to determine its compatibility with local requirements and capabilities.

TEAM REFLECTION

The 2011 EWB Challenge has been a unique opportunity for our team as inexperienced engineering students to familiarize ourselves with the concept of ecologically sustainable development in engineering practice. The challenge to develop innovative and practical solutions for projects with real-world implications will certainly be beneficial in our application of theoretical knowledge in future engineering design.

Overall, this group has done an exceptional job in researching, designing and establishing this project for the EWB Challenge 2011. The motivation and enthusiasm from all members has ensured that the project has developed smoothly over the course of the semester. All members have been willing to contribute thoughts and ideas, as well as contribute their own work into the project. Regular attendance to meetings by all members ensured clear lines of communication, and absence from meetings was always notified prior to their occurrence to ensure no lines of communication were broken. All work assigned to members was completed to a similar high standard. Every member was fully committed to his or her assigned tasks, and the successful levels of communication made it easier for members to seek assistance from other
members. All members were also able to take feedback positively, making sure that if their work were not up to the approved standard, they would aim to improve it.

The team effectively followed a shared mode of leadership, where the team worked in a lateral structure with all members contributing to the development of the project. The team contained no apparent single transactional or transformational leader; instead each member at some point took on this duty in an unplanned manner.

With the group having 6 members, it was difficult to evenly spread out the workload. More extensive parts of the project were hard to divide, and because of large distances between member’s residences, it was hard logistically to complete tasks. During the mid-semester break, the communication lines were lost, and little progress was made at this stage. However, the team quickly went back into action, and fully developed the design of the project in its four components. The group also failed to regularly set agendas and record minutes to meetings. This decreased the efficiency of the team meetings, and slowed the production of design.

While the EWB Challenge has been a rewarding experience in terms of establishing fundamental engineering concepts and professional skills, it could be improved further by positioning the project challenge further along the engineering course. In doing so team members can come equipped with engineering insights and a familiarity with their profession, particularly helpful in determining whether a design solution is technically feasible or economic aspects of the design can be justified.
1.0 INTRODUCTION

This report aims to identify and provide an understanding of the social, economic and environmental issues faced by the Devikulam community that arise from the transportation system of the Nadukuppam Panchayat (region). The Devikulam community as a whole lacks access to an efficient and sustainable mode of transport. There is a clear causal link between immobility and isolation as “key elements of poverty” (Practical Action, 2006). Few transport alternatives are available to the Devikulam community, with only 12 families owning a motorbike and one-third of families owning a bicycle (Engineers Without Borders, 2011a). This limits employment opportunities and potential productivity as well as preventing equitable access to services including health and education. The road network within the Nadukuppam Panchayat is generally inadequate and of poor quality. For example, the most direct route to the nearest major city Pondicherry is impassable during the wet season while other roads are subject to objectionable amenity, with open defecation occurring between villages (Engineers Without Borders, 2011a). Additionally there is no efficient or easy way of transporting water from the village to surrounding areas. It is clear that an inadequate transport system places significant restrictions on the quality of life for local residents.

This report seeks to develop a sustainable and technically sound proposal that will contend with the limitations on quality of life and sustainability imposed by the current system. This proposal will be assessed against an evaluation criterion that is appropriate for the design constraints of the community. This will ensure its compatibility with local needs as well as long-term environmental and economic sustainability.
1.1 BACKGROUND ON EWB

“The EWB Challenge is a design program for first-year University students coordinated by Engineers without Borders Australia (EWB) and delivered in partnership with Australasian universities. It provides students with the opportunity to learn about design, teamwork and communication through real and inspiring sustainable development projects” (Engineers Without Borders, 2011a). Hence, the EWB challenge provides a unique opportunity to create innovative solutions to real-world engineering problems. Engineers Without Borders was established in 2003 and now has over 4,500 members across both Australia and New Zealand. It was founded by a group of enthusiastic engineers from Melbourne who were determined to combine their many talents, resources and interests to change the lives of disadvantaged people throughout the world. It is a non-profit organization which allows underprivileged communities not only within Australia, but also throughout the world, gain access to technological advances, resources and education that allows them to increase their quality of life. The team includes not only experienced engineers but also people such as young graduates, engineering students and even non-engineers. Engineers Without Borders works with a wide range of community groups on a number of common issues. These issues include access to drinking water, sanitation, basic infrastructure, energy, waste systems, engineering education and information communication technology. Although the organization portrays a main focus of contributing new developments to communities of lower socio-economic status, it also tries to ensure that young engineers and especially engineering students gain adequate and real world education as well as training and experience about the career path they are entering.
The EWB organisation has worked collectively with Pitchandikulam Forest to identify a variety of project topics for the 2011 EWB challenge. The initiatives of these project topics are to develop innovative and suitable project solutions that will contribute towards the sustainable development of Devikulam, a remote community in the Pitchandikulam region of India. “These designs, coupled with knowledge and skills sharing, aim to support Pitchandikulam Forest to address the social, environmental and economic issues facing people in the region” (Engineers Without Borders, 2011a). Designs and ideas generated through the challenge make a direct contribution towards EWB’s work with the Devikulam community. The Pitchandikulam Forest is a community located in south India in the green belt of the Auroville international township in Tamil Nadu. It consists of grasslands, nurseries and ethno-medicinal forests in which over 800 different species of plant can be found. The main focus of this community group is to protect, maintain, replant and preserve of what is left of this natural evergreen forest. Pitchandikulam Forest also provides a number of education centres in order to provide the local communities with adequate information and training to raise awareness about hygiene issues such as water sanitation and water supply. Pitchandikulam Forest also promotes local health traditions as well as keeps documents of medicinal plants that may grow and be used within the region. The EWB network coincides closely with their community partners such as Pitchandikulam Forest in order to share their collective knowledge through such design projects.
The problems arising from the transport system of the Nadukuppam Panchayat are extensive, however it is important that most of these elements be addressed in the design solution if any real and lasting benefits to the community are to be realised. Our design objective requires the support and patronage of an appropriate mode of transport. To be effective the solution will have to significantly alter the modal split of transportation in Devikulam. Therefore not only will this transport mode need to be made accessible to the majority of the community, infrastructure and services need to be improved comparably with a viable long-term maintenance plan put in place. A more efficient transport method should potentially be integrated into the network design. Therefore the design problem requires a significant redevelopment of the transportation system currently utilised within the village and its surrounds.

It is important that any project that seeks to resolve these issues is developed at a low capital cost to the community and is both technically and economically viable in the long term. It must promote the concept of ecologically sustainable development and social equity for the community. These design goals are reflected in the evaluation criteria outlined Section 3 of this report. The ultimate aim of the transportation solution is that, if implemented, it will provide immediate and continued improvements to the quality of life of the Devikulam community. The following section seeks to define the scope and extent of the project, with background information pertinent to the design problem, including the local environment, economy and culture of the Devikulam community, will be examined in the Technical Review.
2.1 PROJECT SCOPE

For this project to have a genuine impact on the quality of life of the Devikulam community the transportation solution must provide intra-village and inter-village transport links in order to enable ease of access within the community as well as to external services such as education, resources and trade opportunities. Therefore the scope of this project must extend beyond the bounds of the Devikulam community and will consider the development of a transportation scheme to service the entire Nadukuppm Panchayat. Therefore the project will provide similar improvements to the quality of life of neighbouring villages, namely Nadukuppam, Vandipalayam and Kottikuppam. It is also important for the project to not only consider the inception of a transport scheme but include an effective maintenance plan of infrastructure to ensure the long-term viability of the program. It was decided that an analysis period of 40 years would be adequate to ensure the project is sustainable. The cost of a capital works program of this scale and time period is likely to be significant however such expenditure is necessary to make a real difference within the design area of Transportation. Therefore the budgetary scope of the project will be limited to the amount of external funding that can be acquired to minimise the initial economic impacts of the project on the community.

2.2 TECHNICAL REVIEW

It is critical that the design proposal is developed within the contextual boundaries of the subject area and local community. The following section summarises information regarding the physical, economic and sociocultural context of Devikulam as well as provides a discussion of solutions which have been implemented for design precedents.
2.2.1 ENVIRONMENTAL CONTEXT

The Devikulam community is situated in the Nadukuppam Panchayat of Tamil Nadu, India’s southernmost state. Devikulam has an absolute location of 12° 10’ N and 79° 54’ E. The village lies 26km NNE of Pondicherry, the nearest major city and 106km SSE of Chennai, the capital city of Tamil Nadu (Google Earth, 2010).

Devikulam experiences a typically hot and wet tropical monsoon climate, with historical climate data in Figure 1 of the nearby Pondicherry indicative of this. The mean maximum temperature of Pondicherry between 1996 and 2000 was 33°C while the mean minimum was 24°C (India Meteorological Department, 2000).

![Figure 1: Pondicherry Climate Graph 1996-2000](image)

Data Source: India Meteorological Department

The average annual rainfall over this 5-year period was 1728mm. However it can be seen in Figure 1 that a significant proportion of this precipitation occurs in the months from October to December. This has important implications for the design problem as the monsoonal season is likely to have significant impacts on transport infrastructure, including the possible flooding...
and erosion of road surfaces, as well as for the applicability of particular transport modes.

Devikulam is also susceptible to seasonal low-pressure systems as well as cyclonic storms (and associated high winds and flooding of low-lying areas) which move inland from the Bay of Bengal.

In terms of topography, the village is situated in a relatively flat, low-lying area with an elevation range of around 10-20m above sea level. Located between the village and the coast is a river basin depression, an area used extensively for agriculture. This basin is clear in Figure 2 which represents a transect of Devikulam village to India's eastern coastline. It is in this area that the flooding of roads is most likely to occur in the wet season. Devikulam is remote in that it has few adequate connections to broader transport networks. While the road to neighbouring village Nadukuppam is a tar road of good quality (Engineers Without Borders, 2011c) the closest arterial road (East Coast Road) lies around 6km to the east and the shortest access route is inaccessible in the wet season. The railway is nearly 30km to the west.

Devikulam is located within the Kaluveli Bioregion, north of the Kaluveli Tank (Lake). It is host to a diversity of ecosystems including seasonal wetlands with a salinity gradient from fresh to brackish water and Tropical Dry Evergreen Forest (Iyer, 2011). Figure 3 indicates the location of Devikulam and other settlements in relation to the Kaluveli Tank and its surrounding wetland, riparian and forest habitats. The forests comprise an important bio-resource for the local community, containing over 800 species of plants of which more than 400 have known medicinal properties or are used for construction purposes. Native ecosystems in
the area are currently under threat due to forest clearing and the expansion of agricultural and aqua-cultural activities, particularly prawn farming in Kaluveli. To be considered ecologically sustainable and in keeping with the vision of project partner Pitchandikulam Forest, the transportation design solution needs to protect the integrity of these native ecosystems by minimizing the interference of traffic and infrastructure with habitats such as the Tropical Dry Evergreen Forest.

Figure 3: Kaluveli Tank and surrounds.  
Source: (Pitchandikulam Forest, 2011)

2.2.2 ECONOMIC CONTEXT

As with most rural developing areas, the economy of Devikulam is based upon primary industry activities. Agriculture is the main industry in Devikulam with the majority of the village residents owning their own land, often employing residents of the colony as agri-coolies (Engineers Without Borders, 2011b). Figure 4 represents the spread of occupation in Devikulam, with a significant proportion of people employed in agricultural labour.
As well as the agricultural industry, the economy Devikulam also receives some revenue from the prawn industry. Although this provides job opportunities and income, most jobs in this industry are given to workers who live outside of Devikulam. This industry also has a large impact on the local environment (especially the Kaluveli tank); contaminating ground water supply, affecting agricultural pots as well as using large amounts of water and electricity. Due to an insufficient local demand there is a growing trend of Devikulam youth leaving the community in search of better employment opportunities in nearby cities and towns.

In the village the majority of families own a block of land between 2-5 acres with 75% of villagers owning livestock. This is considerably greater than the people living in the colony with only 3 households own land (Engineers Without Borders, 2011a). On average the residents of Devikulam work between 11-20 days a month and receive an annual income for and between Rs 15,000 (335 AUD) and Rs 30,000 (670 AUD) (Engineers Without Borders, 2011b). Currently, the world international poverty line is $1.25 in terms of purchasing power parity (The World Bank, 2011), with a number of Devikulam residents subsisting at this level of income.

It is imperative that a more efficient transport network with associated services is
developed to improve the trading and employment capacity of the agriculture industry while supplementing current employment with the creation of jobs related to the transport industry. However such stimulation of the local economy must be undertaken in an ecologically and socially responsible manner.

2.2.3 SOCIOCULTURAL CONTEXT

Over 90% of the people in the Viluppuram District, in which the Devikulam village resides, belong to the Hindu religion (District Collectorate, Viluppuram 2011). Within India, adherents of Hinduism maintain a strong emphasis on the Four Order Caste system. Under this system, a person is born into a particular ‘caste’ or social class as a result of the actions executed in their previous life. A person is limited to that caste for life, experiencing social inequality which is considered part of the natural order. It requires acceptance of the doctrine of rebirth and the law of karma, and is followed and customary in the Devikulam village. The conduct of Hinduism includes personal and social duties, involving the pious achieving righteous conduct in the form of abstention from theft and truthfulness. Austerity, self-control, renunciation, non-attachment and concentration are all essential and widely followed disciplines in terms of ethics of the people (Nikhilananda, 2011). Within the Devikulam community the two predominate Caste systems that reside there have an amicable relationship. Both the Scheduled Class, who live in the Colony, and the Most Backward Caste, who live in the Devikulam village, are able to associate with each other at religious functions and other gatherings (Buzza Land Information Systems, 2009). The dissolution of social barriers created by the caste system is important in the equitable development of the Devikulam community. However it is important that development projects are also compatible with the established culture of the local area.
With poor wages, the people of Devikulam must utilise the bare minimum to survive. Most villagers live in mud huts with an average household population of 4-7. Drinking water is only available in the neighboring village of Nadukupppam, as the salinity of the water in Devikulam is quite high due to the lasting effects of the tsunami in 2004 (Buzza Land Information Systems, 2009). The financial situation leaves most of the residents with limited options for private transport with only 5 of the 22 houses owning bicycles in the colony and only 3 owning motorbikes. Families find it difficult to pay for their children to attend school, with transportation cited as being the major cost of education. Around 15 of the 48 houses in the village have bicycles and 11 owning motorbikes (Engineering Without Borders, 2011a).
3.0 DESIGN CRITERIA

The following design criterion is focused around the 2011 EWB Challenge design area of transport. The design can also combine into other design areas if necessary. Based on the research on the background on the EWB and the community of Devikulam in the introduction, the following design criteria were developed. In order to develop a sustainable project, the design criteria can be divided into environmental, social and economic impacts.

3.1 ENVIRONMENTAL

The impacts on the natural environment of Devikulam and the Pitchandikulam Forest to consider include avoiding damage to the ecosystem like their ‘Tropical Dry Evergreen Forest’ and reducing biological diversity. Design needs to be sustainable, so it is able to be maintained. Make use of natural resources without destroying the ecological balance of the area. Considerations of how the design helps people of Devikulam (Engineers Without Borders, 2011a) adopt environmental education and training in rural and coastal contexts.

3.2 ECONOMIC

The design must help develop economic growth in Devikulam. Residents of Devikulam should be given employment opportunities, since many jobs around the village are given to people outside the village. When considering the cost of implementing and maintaining the system, there is no restriction to a design that is affordable by the people of Devikulam if funding for the project can be derived elsewhere. However in order for the chosen design to be successful in
its application for funding it must have a minimal cost over its service life and ideally be instigated at a zero cost to the community. Financial support can come from the Pitchandikulam Forest and the government subsidies for “sustainable initiatives” (Engineers Without Borders, 2011a). Using locally available materials can be more cost effective than importing materials. The mode of transport should be affordable for the people of Devikulam to use the transport system.

3.3 SOCIAL

When considering socially sustainable engineering, it calls for consideration of the cultural needs of groups in the community and also an understanding of community groups’ values, beliefs, priorities and perceptions of engineering work (Dowling et al., 2010). Avoid development in cultural sites. Social equity employment opportunities for Devikulam people can improve their livelihood in the region. Proposed solutions should build on their existing community strengths and consider how the design encourages traditional practice.

3.4 TECHNOLOGICAL

The design must be technically viable and practical to the Devikulum community. Proposed solutions must consider the capacity of the community to resource, operate and maintain the equipment as well as the availability and feasibility of material within the region. The implementation of the project must also be compatible to the area, ensuring technical aspects do not significantly undermine the financial and social stability of the community.

3.5 EVALUATION CRITERIA
This evaluation criteria consists of a grading system which each design option will be graded from 1 to 3, grade 3 being the highest, based on how well the design option “integrates environmental management, economic growth and social equity so that ecological processes (on which life depends) are maintained in state sufficient to meet the quality of life needs of present and future generations” (Dowling et al., 2010). Table 1 is the basis of the design criteria stated above.

**Table 1: Grading Criteria for designs**

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<th>Grade 3:</th>
<th>Design is exceptionally compatible and practical to the community.</th>
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<tr>
<td></td>
<td>Minimal environmental impacts to Devikulam and the Pitchandikulam Forest Region.</td>
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<td></td>
<td>Sufficiently addresses any social equity issues.</td>
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<td>Brings about positive economic growth changes to the area.</td>
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<th>Grade 2:</th>
<th>Design option is fairly compatible and practical to the community.</th>
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<td></td>
<td>May cause limited environmental impacts to Devikulam and the Pitchandikulam Forest Region.</td>
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<td></td>
<td>May address any social equity issues.</td>
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<td>Brings about economic growth changes to the area.</td>
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<th>Grade 1:</th>
<th>Design option is hardly compatible and practical to the community.</th>
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<td>Causes negative environmental impacts to Devikulam and the Pitchandikulam Forest Region.</td>
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<td></td>
<td>Addresses minimal social equity issues.</td>
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<tr>
<td></td>
<td>Brings about negative economic changes to the area.</td>
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4.0 DESIGN ALTERNATIVES

The following section discusses the potential design solutions which have been generated to address the project scope. It details the methodology used to develop alternative solutions and provides a brief description and assessment of some of the alternatives considered.

4.1 METHODOLOGY

To generate solutions, which could potentially rectify the issues facing Devikulam residents, the transportation design problem was broken down into its fundamental components. Through group discussion it was agreed upon that an effective transportation solution would encourage the use of particular modes of transport. A brainstorming and mind mapping activity then produced a range of possible transport modes (see Appendix A). A preliminary feasibility investigation was then conducted in which modes were compared against each other upon the basis of sustainability, economic viability, practicality and effectiveness in addressing the design problem. After an elimination process the most feasible solutions were then selected as design options to be researched. Through discussion it was agreed that each transport mode would require a unique network, infrastructure and services to facilitate its use and these aspects would be included in the analysis of each design option. A success criterion was then formally created against which each option would be evaluated and scored on its design merit. The option that rated the highest in adherence to the success criteria was then chosen as the project solution. A Gantt chart plotting the timeline of our design method can be seen in Appendix B.
4.2 DETAIL OF OPTION 1: BICYCLE TRANSPORT SYSTEM

One transportation solution for the village of Devikulam and surrounding areas is the implementation of a bicycle transport network. This project option would include but not be limited to the following design components:

- Design and construction of a cycle path system with an effective maintenance plan connecting critical nodes of the Nadukuppam District. The system would utilise, extend and redirect the existing road network.
- Provision of appropriate infrastructure along cycle paths, including public amenities and rest areas.
- Educational programs to encourage the benefits of bicycle use and subsidies to ensure the transport option is made accessible to all.
- Encouragement of entrepreneurial activities such as bicycle taxis to provide personal income and enhance the mobility of the elderly, women and children.
- Establishment of a bicycle sale and maintenance centre to facilitate use of this transport option and ensure the long-term viability in the community. This service should also enable the modification of bicycles to increase capacity for taxiing and trade.

The topography of the local area makes the bicycle an excellent transport mode with little elevation change and gentle gradients minimising the physical effort required to commute, making it therefore an attractive transport option. However the monsoonal season could pose a problem for this mode of transport, making commuting more difficult and less comfortable without suitable measures in place. The greatest extent of commuting in the local area would be from the Devikulam village to the nearest major city, Pondicherry. With the current road network, a round trip to Pondicherry could exceed 50km (assuming wet season route is
impassable). The average distance a cyclist is willing to commute is around 5km (Posch, 2009), however this is largely dependent upon the travel environment, road conditions, individual attitudes and the purpose of the commute. Improving community attitudes towards cycling would be an important step in the adoption of the system and increase the distance residents are willing to travel using this mode.

A bicycle transport system could be implemented relatively cheaply due to its nature. Cost of road construction would be reduced as paths can be made narrower to accommodate only 2-wheel vehicles. They could also be made to a lower quality due to reduced load application in comparison other transport modes. For the same reason cycle paths will get worn down far slower due to cycle traffic than rural roads used by heavy vehicles which significantly reduce maintenance costs.

Cycling is a well-established method of commuting among the Tamil population (Posch, 2009) and therefore has the potential to be adopted to increase its modal share of transport. However it will be difficult to change community attitudes sufficiently that a 50km commute to Pondicherry seems feasible. Therefore the transport system will need to reduce the length of this commute if undertaken regularly either with an appropriate all-season pathway or combining with another mode to complete the journey, such as public transport.

Cycling could be considered one of the most sustainable transport options available. After the manufacturing process (which is considerably less than other modes such as car production), the only environmental impacts may include the discarding of parts such as tubes and tyres, most of which can be recycled. Bicycles are responsible for zero emissions, produce little light or noise pollution and are an extremely efficient mode of transport. Therefore from an environmental, social and economic perspective a bicycle transport system represents a viable option for the Devikulam village and surrounds.
Currently, public transport options available to Devikulam residents include a government and private bus service. In particular a service is provided for students to attend school in Marakkanam, 16km from Devikulam. These options are quite expensive to the community and account for the most significant cost of education. There is lack of regular bus services available to the community, which causes difficulty in commuting between villages and the capital city Pondicherry (Buzza Land Information Systems, 2009). The proposed public transport network would provide cheaper and more comprehensive transportation for the Devikulam community between Devikulam and Nadukuppam for resources, work and secondary education (up to 10th standard), Devikulam and Marakkanam for higher secondary education (11th and 12th standard) and between Devikulam and their capital city Pondicherry. This option may include the following:

- The implementation of a school bus service and a regular public bus service into the community. This would require tarring and possible re-routing of the gravel road from Devikulam to Pondicherry and the ongoing maintenance of all the roads that this system would operate on. The service would be required to be of low cost to the community, and could potentially reduce the use of private transport systems, such as motorbikes. This service would increase the availability of jobs to the residents, allowing for easy access to areas where work is obtainable.

- Extending the existing railway network to the Devikulam region by providing a connection south to Pondicherry railway. This could be extended further to create a rail loop to Chengalpattu, which would provide direct rail transport both south towards Vilupurram and Pondicherry as well as northwards to the Tamil Nadu capital, Chennai.
This loop could also provide rail connections for rural villages in the region with similar transport issues to Devikulam.

![Rail Network Map of Tamil Nadu](image)

**Figure 5: Railway Network of Tamil Nadu. Map**  
*Source: (Maps of India, 2011)*

The proposed transport system would involve a regular train service, making travel to the surrounding districts more time efficient and practical for villagers collecting water and other resources. It would also provide employment opportunities to the construction and maintenance of the network. However, for this service to be made possible, a minimum of 25km of railway track would need to be constructed to join onto either the Chengalpattu or Pondicherry railway network (over 50km for the complete loop). Due to the low-lying topography and local wetland environment a series of bridges and extensive ground improvement would be required as well as regular maintenance to the track to ensure the service is not cut off by floods during the monsoon season. At a cost of US$2 million per km for a single track freight line on geologically sound soil in a developing country (Railway Technical Web Pages, 2011), this makes the transport option highly unfeasible to a small community such as Devikulam.
Currently there is insufficient demand within the Devikulam and nearby communities, including Auroville, to develop a viable public transport system that operates within the boundaries of the community, and beyond the community (Posch, 2009). Both public transport systems would require a large amount of money to set up and maintain. A possible problem arising from the initiating of a public transport system is the concern of safety of the users of this service. For buses, potential road accidents would arise from poor driver behavior and poor road and vehicle conditions (Transport Research Laboratory, 1999). For trains, inadequate funding or lack of skilled workers could lead to poor track and train maintenance, creating potential safety hazards to users. Although these services would provide benefits to the community, neither is a cost effective option.

4.3 DETAIL OF OPTION 3: RENEWABLE ENERGY VEHICLES

Another possible design solution involves developing a transport system around the use of vehicles which utilize renewable energy as the principal modes of transport. Such a proposal may involve the following elements:

- The provision of a fleet of electric cars to the Devikulam community. With the introduction of electric cars however, there would also need to be an improvement in infrastructure. The roads would need to be improved and maintained at a suitable level for the use of the electric cars. Sustainable methods of producing and distributing electricity would also have to be built for the Devikulam community in order for them to recharge the electric vehicles when power is drained.

- The provision of solar motorbikes and bicycles, as well as conversion kits to upgrade existing bikes. Electric bicycles only require a few adjustments to a normal bicycle to
operate. Modifications involve the attachment of a motor (usually to the front wheel) powered by a battery (see Appendix C for possible designs). The battery is recharged using a small photovoltaic panel.

The cost of purchasing electric cars is extremely prohibitive, with new electric cars costing around AUS$130,000 and converted cars expense starting from AUS$15,000 (Australian Electric Vehicle Association, 2010). Providing electric cars for the 86 households in Devikulam, as well as the additional cost of improving the road infrastructure and the necessary infrastructure for generating electricity is beyond the scope of this development project and could not be supported by the community with an average per capita income of approximately AUS$420 annually (Buzza Land Information Systems, 2008).

The application of electric bicycles is more feasible as the use of bicycles is already a popular mode of transport in Devikulam. Whilst residents can easily ride from the village to Pondicherry along a gravel track most of the year, during the monsoon season the gravel path is washed away and the villagers must take a longer route. Solar bicycles could help with lowering the physical demand and time taken to travel this extra distance. The electric bicycle would also assist when carrying or even towing goods to Pondicherry. Electric bicycles are much cheaper than electric cars, and have the same advantages environmentally. Another advantage of the bicycle over the cars is that bicycles will have less of an impact on the road surface, so maintenance will be less on the roads between the two villages. However the cost of conversion kits is still expensive in comparison to other possible transport options.
This option involves leaving the transportation system in its current state. No changes would be made to the current road network and maintenance plan. Additional transport modes, services and infrastructure would not be provided or encouraged.

While this may be the most cost-effective option in the short term the current state of transport in Devikulam is inefficient, inequitable and unsustainable. The fact that only 12 families own a motorbike and one-third have access to a bicycle (Engineers Without Borders, 2011c) severely limits the ability of residents to access basic services and is unproductive in terms of trade. Current government schemes, whereby children receive bicycles in the 11th standard to travel to school (Engineers Without Borders, 2011c) are not sufficient to meet the needs of the entire community. Isolation is one of the key elements of poverty (Practical Action, 2006) and thus improving the transport options and as a consequence the mobility of residents is essential in improving their living conditions. It is critical that a mobility plan needs to be developed for the community with clear aims for improving the road network and determining the ideal modal split between transport options to suit the needs of the community.
5.0 EVALUATION OF OPTIONS

The following section will compare each design alternative that has been qualitatively discussed and analysed against the evaluation criteria outcomes outlined in section 3.4. The grading system will provide a semi-quantitative assessment of which proposal is the most applicable to the design brief in terms of social equality as well as environmental and economic sustainability.

Table 2: Evaluation of Option 1 - Bicycle Transport Network

| Grade 3: | Design option is exceptionally compatible and practical to the community. |
|         | Minimal environmental impacts to Devikulam and the Pitchandikulam Forest Region. |
|         | Sufficiently addresses any social equity issues. |
|         | Brings about positive economic growth changes to the area. |
| Grade 2: | Design option is fairly compatible and practical to the community. |
|         | May cause limited environmental impacts to Devikulam and the Pitchandikulam Forest Region. |
|         | May address any social equity issues. |
|         | Brings about economic growth changes to the area. |
| Grade 1: | Design option is hardly compatible and practical to the community. |
|         | Causes negative environmental impacts to Devikulam and the Pitchandikulam Forest Region. |
|         | Addresses minimal social equity issues. |
|         | Brings about negative economic changes to the area. |
Table 3: Evaluation of Option 2 – Public Transport Network

| Grade | Design option is exceptionally compatible and practical to the community. | Minimal environmental impacts to Devikulam and the Pitchandikulam Forest Region. | Sufficiently addresses any social equity issues. | Brings about positive economic growth changes to the area. |
|-------|------------------------------------------------------------------------|------------------------------------------------------------------------------|------------------------------------------------|------------------------------------------------|------------------------------------------------|
| Grade 3: | ☑️ Design option is exceptionally compatible and practical to the community. | ☑️ Minimal environmental impacts to Devikulam and the Pitchandikulam Forest Region. | ☑️ Sufficiently addresses any social equity issues. | ☑️ Brings about positive economic growth changes to the area. |
| Grade 2: | ☑️ Design option is fairly compatible and practical to the community. | ☑️ May cause limited environmental impacts to Devikulam and the Pitchandikulam Forest Region. | ☑️ May address any social equity issues. | ☑️ Brings about economic growth changes to the area. |
| Grade 1: | ☑️ Design option is hardly compatible and practical to the community. | ☑️ Causes negative environmental impacts to Devikulam and the Pitchandikulam Forest Region. | ☑️ Addresses minimal social equity issues. | ☑️ Brings about negative economic changes to the area. |

Table 4: Evaluation of Option 3 – Renewable Energy Vehicles

| Grade | Design option is exceptionally compatible and practical to the community. | Minimal environmental impacts to Devikulam and the Pitchandikulam Forest Region. | Sufficiently addresses any social equity issues. | Brings about positive economic growth changes to the area. |
|-------|------------------------------------------------------------------------|------------------------------------------------------------------------------|------------------------------------------------|------------------------------------------------|------------------------------------------------|
| Grade 3: | ☑️ Design option is exceptionally compatible and practical to the community. | ☑️ Minimal environmental impacts to Devikulam and the Pitchandikulam Forest Region. | ☑️ Sufficiently addresses any social equity issues. | ☑️ Brings about positive economic growth changes to the area. |
| Grade 2: | ☑️ Design option is fairly compatible and practical to the community. | ☑️ May cause limited environmental impacts to Devikulam and the Pitchandikulam Forest Region. | ☑️ May address any social equity issues. | ☑️ Brings about economic growth changes to the area. |
| Grade 1: | ☑️ Design option is hardly compatible and practical to the community. | ☑️ Causes negative environmental impacts to Devikulam and the Pitchandikulam Forest Region. | ☑️ Addresses minimal social equity issues. | ☑️ Brings about negative economic changes to the area. |
Table 5: Evaluation of Alternative Option – No Transport Solution

| Grade 3: | Design option is exceptionally compatible and practical to the community. |
| Grade 2: | Design option is fairly compatible and practical to the community. |
| Grade 1: | Design option is hardly compatible and practical to the community. |

- Minimal environmental impacts to Devikulam and the Pitchandikulam Forest Region.
- Sufficiently addresses any social equity issues.
- Brings about positive economic growth changes to the area.
- May cause limited environmental impacts to Devikulam and the Pitchandikulam Forest Region.
- May address any social equity issues.
- Brings about economic growth changes to the area.
- Causes negative environmental impacts to Devikulam and the Pitchandikulam Forest Region.
- Addresses minimal social equity issues.
- Brings about negative economic changes to the area.
The rationale for the final design solution is based upon the extensive background knowledge outlined in this report which identifies local requirements in terms of transport. Analysis of each design option against our evaluation criteria has successfully enabled delineation of each in terms of their social, ethical, environmental and economic attributes. From this process it has been determined the chosen design proposal which will now be developed is the **Bicycle Transport Network**. As stated previously, this design is likely to involve the integration of a variety of activities, however, will be centrally focused on developing a transportation system for Devikulam around bicycle use.

From the evaluations conducted, the **Public Transport Network, Renewable Energy Vehicles**, and the **No Transport Solution** design options were deemed ineffective in meeting a sufficient number of Grade 3 requirements necessary to fulfill the design brief. Therefore, they will not be researched or promoted further as potential solutions for the final report.
The selected project will involve the amalgamation of a number of activities that will collectively enable sustainable transportation within the Nadukuppam Panchayat. These include:

- Cycleway Construction and Maintenance Scheme
- Bicycle Provision
- Bicycle Sale, Maintenance and Retrofitting Centre
- Sustainable Transport Education Program

The Cycleway Construction and Maintenance Scheme will be the most significant part of the project in terms of scale and capital expenditure. The provision of physical infrastructure is also the most critical aspect in realising the goal of sustainable transportation with the community. The design aspects of the network will be based upon a number of factors including cost analysis, local requirements and conditions as well as structural and ecological sustainability. The Bicycle Provision element intends to provide the families of Devikulam and surrounding villages with equitable access to this sustainable mode of transportation at a reduced or zero cost to the community. This will be achieved through the extension of government funding programs, collection and charitable organisations. The Bicycle Sale, Maintenance and Retrofitting Centre is another important element of the project which will ensure the continued viability and expansion of bike transportation within the local area. Complementing these foregoing project elements will be an education program at school and community levels that will seek the enculturation of sustainable ideals and work towards the eventual adoption of bike transport as the principal mode.
7.1 CYCLEWAY CONSTRUCTION AND MAINTENANCE SCHEME

The principal aim of the project is to provide the Devikulam community with an efficient and sustainable transportation system. To facilitate the use of bicycles as the predominant mode of transport a cycle path network needs to be developed that will:

- Support the commuting requirements of the Devikulam community as well as surrounding villages in the Nadukuppam Panchayat.
- Be developed at a low capital cost to the community.
- Be easily and cost-effectively maintained at a standard sufficient standard to support low volumes of bicycle traffic.
- Minimise the impact of infrastructure on the local environment.
- Have a relatively long service life.
- Encourage positive interactions between the caste systems.

7.1.1 IMPLEMENTATION

The scope of the cycleway project is to include the entire Nadukuppam Panchayat and will service four villages within the region: Devikulam, Nadukuppam, Vandipalayam and Kottikuppam (see Appendix C). Determining the ideal location of the entire cyclepath network around the Panchayat would require extensive community consultation and involvement. However an initial step in the implementation of the network would be the replacement of existing roads which have fallen into disrepair. Geographical Information System (GIS) data compiled by Pitchandikulam forest indicates that there is approximately 11.3km of roads graded as only fair or poor quality which would be ideal candidates for replacement with a reliable concrete cycleway. To further improve inter-village transport additional road connections are also proposed (see Appendix C). The 6km dry season route which extends from Devikulam to the East Coast Road is currently unsealed and prone to washouts. Therefore this
road will also require rerouting and replacement to provide a reliable, all season route to the regional capital of Pondicherry. From this initial stage of development the network will require the construction of approximately 20km of cycle path. To determine the most appropriate cycleway for local requirements as well as economic and environmental constraints it is necessary to perform a life cycle analysis of the available options.

### 7.1.2 SURFACE TREATMENTS

The usual types of treatments used for cycleway construction are asphalt, chip/sprayed bitumen seals, concrete, and unsealed gravel (granitic or limestone) surfaces (TSA 2001):

**Concrete:** a high strength cement bound layer over a lower strength granular sub-base. Concrete may be plain or reinforced.

**Asphalt:** well graded non-plastic material bound with between 5 – 7% bitumen produced by a hot mix processing plant and applied over a granular base.

**Chip/sprayed bitumen seal:** a water resistant surface formed by placement of a layer of stone chips rolled onto a thin layer of bitumen (with or without a geotextile) applied over a granular material base.

**Unsealed/gravel:** consists of aggregate up to a 20 mm stone size and is commonly either crushed limestone or granitic sands.

### 7.1.3 LIFE CYCLE ANALYSIS

The selection of path material for the cycleway is critical in determining the cost of construction and maintenance, life-span and environmental impact of the road network. To ensure an
acceptable service is provided in terms of the structural and functional performance of the path, a life cycle analysis of the cycleway must consider a number of competing factors (ABC 2006):

1. **Physical characteristics of the local area:** The climatic, subgrade and terrain conditions of the site have significant implications for path construction. Due to the monsoonal climate of the local area materials must be selected to resist periodic inundation by scouring. Concrete is an example of a material with excellent resistance to erosion by inundation. Unsealed gravel paths have poor resistance to flooding which erodes the aggregate (requiring re-application) and causes deep rutting. The predominant soil series of the Vilupuram District is a type of sandy clay loam (AED n.d.). The ability of a soil series to withstand the loads placed upon it as the subgrade for a road is determined by its California Bearing Ratio. The CBR is a ratio of the force required to achieve a given penetration of a prescribed piston into a soil compared to that required to achieve the same penetration into a standard sample of crushed rock such as limestone (Roberts 2006). Sandy clay loams are typically characterised by a CBR range of 6-7%. Soil horizons with CBR values less than 10% are classified as weak subgrades (ABC 2006), however if greater than 2% do not require stabilisation. Consequently the CBR of the subgrade determines the required sub-base thickness for the path to ensure acceptable structural performance. For a subgrade CBR between 5-10% the required sub-base thickness is 150mm (ABC 2006). On weak, expansive (clay) soils concrete is seen as the ideal surface treatment. In terms of terrain, the gently sloping local relief is unlikely to place restrictions on the path design specifications.

2. **Expected pavement loads:** In the case of cycle paths users place negligible loads on the pavement, therefore the loading conditions considered in calculation are based on
anticipated motor vehicle traffic from mostly maintenance and service vehicles. In terms of our project the commuters that will be serviced by the network are relatively small rural populations with main modes of transport being bicycles, motorbikes, carts and pedestrian activity. Low volumes of this type of traffic are unlikely to place stressful loads on the pavement.

3. **Cost:** The cost of path infrastructure includes the initial capital cost to construct the cycleway as well ongoing maintenance costs. The capital cost of path infrastructure is not necessarily solely determined by the physical location, structure, materials and usage. Costs will also be subject to variations, for example through the availability, suitability and performance of materials. There are two different potential economic approaches to road construction. A high-capital/low maintenance cost path may produce the lowest life-cycle cost, however capital constraints may mean that only a lower-capital/higher maintenance option is feasible. Alternatively a low-capital/high maintenance cost path produce the lowest life-cycle cost, but the future maintenance costs may not be able to be supported by anticipated future budgets (ABC 2006). The economic criterion for our project is to provide a viable transport option that is sustainable for the long term. This requires that maintenance costs over the service life of the network are minimised and therefore higher spending is preferred to mitigate downstream budgetary impacts.

Figure 6 compares the typical construction, maintenance and whole-of-life costs for a cycle path with the following specifications:

- 2-way cycleway, 3m width
- Weak subgrade (CBR < 10%)
- Low traffic loading
The foregoing Figure 6 represents typical costs and does not account for differences in local resources and labour as well as the conditions of the project context. For example the gravel surface treatment seems by far the cheapest from this analysis, however due to the likelihood of monsoonal inundation and consequent erosion maintenance costs for this surface would increase significantly. This preliminary analysis also does not consider the difference in service life provided by each option and therefore the difference in salvage value at the end of the analysis period.

4. **Pavement design and surfacing life expectancy**: Different surface materials and sub-base thicknesses produce different expected path service lives. For example a typical concrete cycleway is expected to last 20 to 40 years, asphalt 10 to 20 years and sprayed seal 5 to 10 years (ABC 2006). Longevity of the cycleway is important in fulfilling the sustainability criteria of the project and therefore a longer service life is considered a valuable attribute.

5. **Maintenance treatments adopted over the service life**: The different properties of each surface material produces unique maintenance issues caused by use or environmental conditions. This affects the frequency of intervention for maintenance and associated
costs. Table 6 illustrates typical path defects experienced for different treatment materials and their associated maintenance activities.

### Table 6: Typical Defects and Associated Maintenance

<table>
<thead>
<tr>
<th>Pavement type</th>
<th>Routine</th>
<th>Periodic</th>
<th>Frequency (years)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Granular (unsurfaced)</td>
<td>1. Erosion/washouts after rain</td>
<td>1. Localised reconstruction of soft spots, gravel topping and reshaping 2. Restoration of cross fall</td>
<td>Every 3 - 5</td>
</tr>
<tr>
<td>Asphalt surfaced</td>
<td>1. Delamination - then pothingling 2. Edge break - pavement/unsealed shoulder interface 3. Deformation and cracking due to intrusion by tree roots</td>
<td>1. 30 mm asphalt overlay - resurfacing 2. Patching 3. Regulation of depressions</td>
<td>5 - 20</td>
</tr>
</tbody>
</table>

6. **Path smoothness or ride quality**: To ensure local benefaction of the cycleway the design must also consider the performance criteria demanded by users. The local community is unlikely to be committed to using the transport network if it is difficult or uncomfortable to commute on. Concrete and asphalt are the surfaces preferred by cyclists due to their low rolling friction and energy dissipation due to vibrations. Sealed granular and
unsealed gravel surfaces are regarded as inferior because of their higher rolling resistance and increased vibrations caused by a larger aggregate size. Surface condition can be affected by cracking of surfaces, spacing of joints, vertical joint displacement and joint condition (ABC 2006). Therefore, an adequate maintenance schedule is required to keep the surface in a condition conducive to riding.

7. **Sustainability:** In the life cycle analysis of the cycleway it is important to consider the environmental impact of its construction and maintenance in terms of resources consumed and emissions produced by aggregate production and vehicles used for excavation, construction, and maintenance. A compromise needs to be found between economic viability and environmental impact to ensure that project development is ecologically sustainable. Figure 7 indicates the amount of aggregate required and expected carbon dioxide emissions for each surface treatment.

![Figure 7: Sustainability of Surface Treatments](image)

*Data Source: Australian Bicycle Council 2006*
Concrete: This surface treatment is the hardest and most durable, providing the longest design life (around 40 years) and lowest maintenance costs of all options. Concrete will also provide superior performance on the wet, weak sub-grade of the local area and greatest resistance to inundation and scouring. However, although simple to form, this option also incurs the highest construction costs and if structural failure occurs within a slab the entire panel requires replacement. While this treatment is responsible for the greatest emissions it utilises the least amount of aggregate resources, important as local sources may be scarce.

Asphalt: Asphalt surfacing provides a hard, smooth surface with a reasonable lifespan of around 20 years. The absence of joints in the surface often makes it the preferred surface over concrete in terms of commuter comfort. However on weak sub-grades, especially expansive clays such as those found in the local area, a more intensive maintenance program is required to ensure a flat, smooth surface and a thicker pavement is usually required. Conversely repairs are often inexpensive as they can be localised to a particular area. Asphalt is also susceptible to surface failure and erosion as a result of periodic inundation. Asphalt surfacing is responsible for far less emissions in comparison to concrete however uses the most resources of all options.

Unsealed/Gravel: This alternative offers the cheapest construction costs of all options and while maintenance is the most frequent and intensive it is relatively cheap due to its nature (requiring only periodic sweeping and resheeting to replenish granular surface material). However this surface is unrideable when wet is extremely susceptible to washouts, rutting and surface erosion following heavy rainfall such as that experienced in the local environment. While ideal for gently sloping grades, in any condition this surface provides inferior performance. Therefore
this surface treatment, while inexpensive and responsible for the least emissions, is considered unsuitable to the local environment.

**Chip Seal:** In terms of construction and maintenance costs a sealed granular surface is comparable to (although less than) that required for asphalt while resource use and emissions are similar to those of the gravel surface. In terms of ride comfort a sealed granular surface is between these two options. A smaller stone size can be used to improve surface smoothness however this results in a shorter lifespan for the seal. The addition of a geotextile can counteract this effect and improve ride quality but will proportionally increase construction costs.

To select the ideal design material for the project cycleway each surface was graded against the foregoing performance criteria. The criteria were then weighted to reflect the varying importance of outcomes within the project context. The result of this process is shown in figure 8.

![Weighted Score of Surface Treatments](image)

**Figure 8: Weighted Scoring of Surface Treatments**

**7.1.5 DETAILED COST COMPARISON**
From figure ( ) it was determined both the asphalt and concrete surfaces were possible candidates for the design project. To differentiate them on an economic basis it was necessary to perform a more rigorous present cost analysis on the two options, accounting for both construction and maintenance expenditure for equivalent scenarios. The following cost comparison in Table 7 has been adapted from economic data collected by Geopave, VicRoads in 2000 (see calculations in Appendix D) and consider relatively pessimistic maintenance scenarios. In order to compare the two alternatives over the same analysis period the useful life of the asphalt path (20 years) must be extended to that of the concrete path (40 years) and therefore requires replacement at the end of 20 years.
### Table 7: Cost Comparison of Asphalt and Concrete Surface Treatments

<table>
<thead>
<tr>
<th>Maintenance/rehabilitation scenario</th>
<th>Year 3 - crack sealing over 30%</th>
<th>Year 6 - asphalt regulate 5%, geotextile seal</th>
<th>Year 10 - patching of severe shape loss areas 5% of area</th>
<th>Year 13 - patching 5%, regulation 50%, geotextile seal</th>
<th>Year 20 - reconstruction of pavement</th>
<th>Year 23 - crack sealing over 30%</th>
<th>Year 26 - asphalt regulate 5%, geotextile seal</th>
<th>Year 30 - patching of severe shape loss areas 5% of area</th>
<th>Year 33 - patching 5%, regulation 50%, geotextile seal</th>
<th>Year 40 - patching 5%, regulation 50%, geotextile seal</th>
</tr>
</thead>
<tbody>
<tr>
<td>Initial cost $16.61/m²</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Maintenance/rehabilitation scenario</td>
<td>Year 5 - joint resealing 1 per 50 m</td>
<td>Year 10 - slab replacement 2%, joint grinding 1 in 36 m, resealing 1 per 50 m</td>
<td>Year 15 - slab replacement 2%, joint grinding 1 in 36 m, resealing 1 per 50 m</td>
<td>Year 20 - slab replacement 5%, joint grinding 1 in 36 m, resealing 1 per 50 m</td>
<td>Year 25 - slab replacement 5%, joint grinding 1 in 36 m, resealing 1 per 50 m</td>
<td>Year 30 - slab replacement 5%, joint grinding 1 in 36 m, resealing 1 per 50 m</td>
<td>Year 35 - slab replacement 5%, joint grinding 1 in 36 m, resealing 1 per 50 m</td>
<td>Year 40 - slab replacement 5%, joint grinding 1 in 36 m, resealing 1 per 50 m</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Net Present Value approx. = $46.17/m²</td>
<td>Consider alternative scenario:</td>
<td>Best case scenario - reconstruction not required</td>
<td>Net Present Value approx. = $41.34/m²</td>
<td>Consider alternative scenario:</td>
<td>Best case scenario - no maintenance</td>
<td>Net Present Value approx. = $32.45/m²</td>
<td>Net Present Value approx. = $35.34/m²</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Using a pessimistic maintenance scenario the concrete path is the cheapest alternative in terms of present value. Figure 9 indicates the economic impact of taking into account the difference in service life in comparison to the preliminary cost analysis of Section 7.1.3 which ignored the effect.
It is only in considering the best possible scenarios (no maintenance required for the concrete path and the asphalt path lasting the same 40 year service life without rehabilitation) that the asphalt treatment works out marginally cheaper. However in realistic terms the design alternative from a ‘whole-of-life- costing’ approach that is most applicable to the project is concrete surfacing. This is in accordance with the economic rationale defined at the beginning of this section: Despite the high initial cost for construction of infrastructure, this is compensated by reduced maintenance expenditure over an extended lifetime.

7.1.6 DESIGN SPECIFICATIONS

The cycleway will comprise of a 3m-wide, two-way shared cycleway/footpath. In accordance with recommendations of the Cement and Concrete Association of Australia the path will consist of a 100mm surface layer of plain concrete pavement on a 50mm gravel sub-base and optional 150mm capping layer of the sub-grade. The cross-section of the path can be seen in
Figure 10. Transverse contraction joints will be placed at 4m intervals. A one-way 2% crossfall in the direction of natural drainage will allow for the removal of water from the path surface (ABC 2006) without requirement for expensive stormwater infrastructure.

![Cross-Section of Final Path Design](image)

**Figure 10: Cross-Section of Final Path Design**

### 7.1.7 MAINTENANCE PLAN

The following graph in Figure 11 represents a potential maintenance estimate required for the concrete cycleway for the duration of its predicted 40 year service life based upon the assumption of relatively low traffic volumes and associated loading. Note that the expected maintenance scenario is considerably more optimistic than that considered in the present cost analysis of Section 7.1.5 and therefore expected whole-of-life costs will be reduced. The net present value of this maintenance schedule is approximately $1.88/m² (see calculation in Appendix D).
Table 8 details the maintenance procedures recommended by the Australian Bicycle Council for surface defects unforeseen in the maintenance schedule. If the cycleway is well designed for local conditions then such defects should be rare and therefore extra maintenance costs will be negligible.
Table 8: Unforeseen Maintenance Procedures  

<table>
<thead>
<tr>
<th>Defect</th>
<th>Treatment</th>
</tr>
</thead>
<tbody>
<tr>
<td>Vertical displacement &lt; 8 mm</td>
<td>No action required.</td>
</tr>
<tr>
<td>Vertical displacement 8 - 25 mm</td>
<td>The elevated joint should be ramped to improve ride quality by the use of cold mix.</td>
</tr>
</tbody>
</table>
| Vertical displacement > 25 mm  | Isolated displacements on sections of the driveway in good condition will have a cold mix ramp installed.  
                                    | Extensive areas of displacement near vegetation install root barrier and replace concrete.  
                                    | In areas where tree roots are unable to be cut either install cold mix ramps or remove concrete and replace with cold mix. |
| Joint/crack widths < 8mm       | No action.                                                               |
| Joint/crack widths 8 - 20mm    | Individual cracks can be filled with grout.                              |
| Joint/crack widths >20mm       | Fill cracks with cold mix concrete if the path is still serviceable.     |
| Ponding of water               | May be caused by subsidence of ground below cycleway and will require alteration of surrounding landscape to maintain crossfall. |

The cycle path will also require routine mechanical or manual sweeping to remove debris and sediment deposits, line re-marking, signage updating and vegetation to ensure the continued serviceability of the path. Generally concrete cycle paths require minimal maintenance during their service lives if the initial capital expenditure is sufficient to provide quality infrastructure. Assuming that construction costs are $35.34/m² and maintenance costs are limited to those included in Figure 11 then the whole-of-life cost for the concrete pathway will be $37.22/m² (see calculation in Appendix D).
Providing the Devikulam community with access to bicycles is essential to the success of the project. As only 1/3 of the families in the Devikulam community currently own a bicycle, there is a great need for more bicycles to be made available. For the bicycles to be made the predominant mode of transport, a cheap and sustainable means of obtaining them needs to exist. Currently, the average cost of a brand new bicycle in India is around Rs 3 000 – 4000. The community would be unable to afford this cost, especially when taking into consideration essential bicycles accessories, including pedals, basket, stand, rack, helmet, and chain and lock.

**7.2.1 IMPLEMENTATION**

Obtaining the bicycles would involve the initiation of a community project based in Devikulam that covers the surrounding villages in the Nadukuppam Panchayat, as well as Pondicherry, involving the public donation and collection of old and broken bicycles. Volunteers from the Devikulam village would be required to seek donations from households and businesses, as well as search alleyways and landfill for dumped bicycles and any parts that can be used in their construction. In Indian cities, including Pondicherry, bicycle ownership is between 30 – 50% (Bicycle Partnership Program 2011). Taking this figure into account indicates that there would be a large availability of unused, old and broken bikes and their accessories dumped within the city and surrounding areas. Sufficient observation would allow many bicycles to be sourced from urban areas. If permitted, the bicycles would be transported back to the village for reconstruction and repair.

The government-run scheme involving students in 11th standard receiving bicycles (Engineers Without Borders 2011c) would be another source of obtaining the bicycles. This would promote students in the Devikulam and surrounding villages to maintain their
education in order to gain access to a quality bicycle which they can use for a variety of purposes, adding to the village bicycle supply.

Many international organisations provide bike donations to needy rural communities in third world countries. If a liaison was made with organisations such as “Bikes for the World” or “Australian Goodwill Bicycles” (International Bicycle Fund 2011) by the community then there is a possibility that provision of recycled bicycles and spare parts would be donated for the Devikulam community’s use.

Bank loans could provide access to money if particular parts needed to be bought. These loans would be a joint cost with all the Devikulam community in order for them to be paid off.

### 7.2.2 RENOVATING THE BICYCLES

Depending on the state of the acquired bicycles, various renovation methods would need to be applied. These include:

- Renovating bicycles so that they are in a decent state to ride
- Stripping down bicycles beyond repair for spare, usable parts. These parts would be used to provide stock components for the maintenance center to be used in the repair of other bicycles.
- Attaching required bicycle accessories to suit the individual that is ridings’ needs. These include, but are not limited to, pedals, basket, child seating, stand and rack.
- Providing helmets to the riders for safety purposes, as well as a chain and lock for security needs.

### 7.3 BICYCLE EDUCATION PROGRAM
EWB project partner Pitchandikulam Forest currently provides environmental education programs at the Nadukuppam Environmental Education Centre (NEEC), the Coastal Environmental Education Centre (CEEC), and at the Auroville Botanical Gardens. The main focus of these programs is to improve the academics standards of schools in the local region while “ensuring sustainable development for the area's sensitive Tropical Dry Evergreen Forest” (Pitchandikulam Forest 2011). Under the current program Nine Schools around Nadukuppam are participating with 150 students receiving direct contact with NEEC staff and a further 2000 students gaining environmental awareness from the educational programs indirectly (Pitchandikulam Forest 2011). These programs provide a unique opportunity to encourage the use of bicycle transportation within the local community.

7.3.1 IMPLEMENTATION

This element of the project design involves incorporating the message of bicycle use into the Pitchandikulam Forest education program in order to integrate the transport mode into the lifestyle and culture of the local community. The promotion of a bicycle culture through a Bicycle Education Program is in keeping with the principles of ecological sustainability espoused by Pitchandikulam Forest and provides a practical way for students to apply the conservation principles they learn from the program. It has the added benefit that it will use current teaching methods, resources and initiatives and so can be undertaken without the requirement for further economic or resource support. There are a number of ways by which the message can be applied:

- The current program incorporates the use of exposure visits by the schools to the local remnant forest at Kurumpuram and to the medicinal forest at Pitchandikulam. Such exposure visits could become guided bicycle tours for students to integrate the idea of sustainable transportation in the local environment.
• Schools receive intensive classes on conservation topics such as the history of the Tropical Dry Evergreen Forest and the water cycle. Therefore the concept of bicycle transportation could be introduced into the current program as an addition to the environmental education curriculum. This topic should outline the environmental as well as personal health and enjoyment benefits of using bicycles over other modes of transport.

• To improve participation and adoption of the mode of transport the educational classes could include a variety of interactive activities, such as inviting students to use a stationary bicycle to power lights or other appliances and bicycle races.

The principal aims of the Bicycle Education Program are not only to espouse the environmental benefits of bicycles as a transport option but will also consist of practical components in order to keep the path a safe and comfortable environment. As the inception of the program coincides with the inauguration of the bicycle path, a large emphasis of the program will be based on cycle path etiquette. During this phase of the program students will learn how to share the path with others by riding on the left hand side of the path as well as riding in single file if needed. Students will also learn how to pass slower cyclists safely, this includes ringing their bell as you approach them so they know you are coming and safely passing them on their right hand side. Participants must also be reminded that although this path is mainly built for bikes, pedestrians and maybe even some motor vehicles will be used on or within a close vicinity of the path. To cater for this students will be taught how to ride at a safe speed and how to interact politely with vehicles and pedestrians as well as other cyclists.

The program will cater for both children and adults of all ages and of all skill levels ranging from beginners who are just learning to ride bikes to people who are looking to improve on their skills. Bikes and helmets will be provided if needed. This will also ensure that
the students are learning on safe equipment that has been properly maintained and cared for. A qualified bicycle instructor will also be provided in order to ensure that the students are obtaining appropriate information. The instructors will organise games and quizzes to keep everyone entertained and increase their information retention and promote bicycles as a fun, safe mode of transport. Classroom style handouts will also be provided in order to complete the theory side of the education program.

Students will learn about:

I. **The ecological benefits of bicycles** (in the context of the Pitchandikulam Forest environmental education program)

II. **The mechanics of a bicycle**
   - All the different parts of the bike and how they work

III. **Bicycle maintenance**
    - How to look after their bike
    - How to make minor repairs

IV. **How to ride safely**
    - Learning to ride a bike
    - Riding a bike with sufficient safety gear. i.e. helmet and light and fluorescent vest if riding in the night time

V. **Riding on the road with traffic**
    - Riding on the cycle path
    - Riding within 1m of the curb
    - Riding around parked cars
    - Scanning the road ahead
    - Complying with road rules
7.4 BICYCLE MAINTENANCE CENTRE

To fully achieve the ‘bicycle culture’ that this project aims to instill into the Devikulam community, the whole project must be sustainable for local people. Care must be taken into ensuring the maintenance of the cycle paths to be constructed, but to ensure greater sustainability; the bicycles upon which community transport will rely must be properly and regularly maintained. Therefore, this project must also involve the construction and operation of a Maintenance Centre for the repair and general maintenance of bicycles and their accessories.

7.4.1 IMPLEMENTATION

A number of mechanics would need to be employed in order to operate the Maintenance Centre, preferably sourced from the local community. At least two mechanics would need to be initially trained/employed, with more later trained as the demand for their services increased. After the initial skilling of technicians, the maintenance center should become a self-sustaining profession with further technicians educated from the experience of others. The role of each mechanic would be to provide services to the community to maintain, repair and salvage bicycles for use by the people of Devikulam and surrounding villages.

The mechanics could also expand their role at the Centre by constructing and retrofitting of trailers or panniers to the bicycles. These accessories to the bicycles would benefit the people of Devikulam who transport goods for trade with neighbouring villages and urban centers. The additional load capacity would improve the efficiency of their commuting and hopefully benefit the community economically.
The Centre could also expand into the manufacture of rickshaws: a tri-cycle that has a seat behind the driver's, for passengers. The rickshaws would serve as either a form of taxi for the people of Devikulam (particularly for women, children and the elderly), or as a way to transport goods by removing the passenger seats and leaving space to hold a load. Again, the proposed rickshaws would hopefully improve the efficiency of the trips made to adjacent villages, by being capable of carrying more in a shorter amount of time.
The initial development stage for the cycleway outlined in Section 7.1.1 will necessitate the construction of approximately 20km of concrete pathway. Accounting for the scheduled maintenance plan defined in Section 7.1.7, the total capital and operating costs for construction and maintenance of the path over its 40 year service life is approximately $2.23 million (see calculation in Appendix D). This estimate relies upon generic costs for resources, equipment and labour and the local economic situation may affect this cost. Additional capital expenditure will be required for signage and necessary public utilities to support cycle infrastructure, including a toilet facility between the villages of Devikulam and Nadukuppam.

For the Cycleway Construction and Maintenance Scheme to be economically viable significant financial support must be secured from external sources. In 2000 The Prime Minister’s Rural Road Program (a partnership project between the International Development Association and India’s Central Government) was launched to improve the connectivity of India’s rural areas with the provision of all-weather access roads (World Bank 2008). To date the program has been responsible for the provision of 300 000 km of either new or improved rural access roads connecting 73 000 habitations, with another 375 000 km being constructed and 372 000 km improved at a cost of $40 billion (World Bank 2011). A condition of this program is that it is only economically feasible to improve connectivity to habitations with populations in excess of 500 people. While the village of Devikulam has only 368 residents (Gramap ), by incorporating the other villages of the Panchayat into the scheme this condition may be satisfied. Under this program the $2.23 million necessary to implement the cycleway concept is insignificant to the funding that has been outlaid to enhance India’s rural roads.
The collective economic impact of the other three components of the project is relatively small in comparison to the cycleway scheme. Bike provision will rely principally on recovering bicycles from nearby urban centres (which will incur only a cost of transportation), donations from charitable organisations and government programs. The education program will utilize existing teaching resources while the maintenance centre, once established, will become a self-sustaining entrepreneurial activity with technicians paid for their services by customers.

8.1 BENEFITS OF THE CYCLEWAY CONSTRUCTION AND MAINTENANCE SCHEME

The construction of the cycleway network throughout the Nadukuppam Panchayat will provide notable benefits to both the communities within the region and the environment. In 2000 74% of India’s rural population was not fully integrated into the national economy due to inadequate transport connections from hinterland areas to urban centres (World Bank 2008). This cycleway project will enhance the connectivity of villages to surrounding areas. Increased mobility has the potential to open market and employment opportunities to local residents, improve access to resources (especially drinking water) as well as the accessibility of social services of which the most significant are education and health. The cycling network will enable the acceptance of a ‘bike culture’, enhancing inter-village relationships and promoting the values of sustainable transport and healthy lifestyles. Providing a transport network that is equitable to all will assist in dissolving the economic and social caste barriers within the community. It will be equally accessible to all citizens, regardless of caste, and so will encourage positive and cooperative interactions between all castes on a daily basis. As the majority of the initial development stage involves supplementing or replacing existing roads within the transport network of the Panchayat, the cycleway construction and maintenance
scheme minimises its impact on the local environment. Significantly the cycleway will require little land clearing or additional land usage other than that occupied or adjacent to current roads. Therefore despite the extent of the network it will cause virtually no destruction of local habitats, disrupt the agricultural capacity of local producers or encroach upon property boundaries. The implemented maintenance plan also has the potential to provide periodic employment for local workers throughout the design life of the path. The design of infrastructure based upon its whole of life of life costs has the additional benefit of not only maximizing return on outlaid capital but minimizing natural resource usage. By favouring bicycles as the predominant modal share of transport in the region the cycleway will help to reduce emissions caused by other modes such as cars, motorbikes and buses.

8.2 BENEFITS OF BICYCLE PROVISION

For those families that own a bicycle, access is primarily given to the men of the family. As a direct result of this, transportation costs discourage rural Indian families from sending girls to school, despite schooling costs being free. Around 50% of girls in rural India drop out of school after 5th class (Global Giving 2011), with only a small percentage reaching 12th standard. The provision of bicycles to these girls through the community project would allow them the right to an education, giving them the chance to free themselves from poverty. Provision of bicycles would also allow the boys of the community a stronger chance of a higher education also.

The bicycles can be used to carry produce and other stock at long distances to places such as Pondicherry for sale, allowing quicker and more efficient transport and transactions. This promotes economic growth within the region and allows more finance into the village, decreasing the percentage of poverty.
As a quicker mode of transportation than walking, the bicycles save time and energy for the Devikulam community. This allows for more time working on the farm, helping around the house, and for the children, focusing on school work, among other daily duties. The increase in time available is of great benefit to all as it improves the production within the community. This promotes economic growth within the region and allows more finance into the village, decreasing the percentage of poverty.

8.3 BENEFITS OF THE MAINTENANCE CENTRE

The operation of a Maintenance Centre would keep the bicycles in operation for an extended period of time. By regularly maintaining the bicycles it will save purchasing new bicycles when the parts on original bikes have become worn. The centre is also environmentally sustainable in the sense that bicycle frames, wheels and parts are recovered that would have otherwise ended up in landfill. The Maintenance Centre would be a job source locally as a number of mechanics would need to run the center, and possibly administrative personnel to monitor the usage of the bicycles and equipment needed to maintain the bicycles.
9.0 IMPLICATIONS OF PROJECT

9.1 ENVIRONMENTAL IMPACTS

The cycleway requires a great number of resources for its construction, contributing to greenhouse emissions and consuming unrenewable resources. Concrete contributes over 80 tonnes/km of carbon dioxide emissions into the atmosphere and consumes 100 tonnes/km of aggregate. Sourcing the aggregate involves mining, processing and transport processes, each using large quantities of energy. The mining of aggregate and concrete resources has a considerable effect upon the ecology of the areas that contain these resources, including forests and riverbeds. The production of each component of concrete (cement, aggregate and water), plus any additives needed, consumes a substantial amount of energy in total. This energy primarily comes from the burning of fossil fuels, releasing a vast amount of emissions into the atmosphere. Increased emissions contribute to global warming, which has an adverse amount of effects to the natural and physical environment. Another factor that needs to be considered is the local availability of these materials. If unable to be sourced locally, the transportation of these materials needed to construct the cycleway would be at an increased distance, further contributing to greenhouse gas emissions due to the energy consumed via transportation.

The cycleway path may potentially be routed over areas where tropical forest exists. If this was the case, it would lead to the destruction of the natural environment, a vital resource to the Devikulam and surrounding community.

9.2 SOCIAL IMPACTS

Despite the project generating lower future costs for the community, the initial expenditure on the implication of the project will come at a significant setback to the community financially. The greater costs of the project, significantly the $2.23 million required to complete the
cycleway, rely on the funding by external organisations. The bicycle maintenance centre requires the services of mechanics to service and renovate the bikes as well as a possible administrative position to monitor their usage and so money would be needed to train and hire these services. Also at a loss to the community is the initial setting up costs of the centre, and the cost of any parts or accessories that need to be bought for the bikes. For the cycleway’s construction to proceed, funding for the project must be provided by The Prime Minister’s Rural Road Program, while the bicycle provision must come from donations from goodwill organisations. Both initial and maintenance costs must be provided for by these organisations, otherwise the project will be significantly expensive for the community and unable to proceed.

Consultations within the village, between surrounding villages, and with outer organisations are required for the success of the project. Communication barriers may be of an inconvenience to the project. These barriers include language barriers, cultural differences and divisions between castes. Volunteers from within the community will be required as liaison officers and to source and obtain the bicycles. If no one is willing to act in these duties then the project will be unable to proceed.

Return on the investment in terms of the capital spent for the community is hard to predict in the long term, and potentially may generate a loss of income to the Devikulam area, especially initially during and after the project is completed. The speed that the project proceeds at depends on the success of community consultations, the length of time it takes to gain funding, the time taken to source required materials, and on the quality of the labor hired. Potentially, the project may take several years before it is complete. The community must maintain patience; otherwise tensions within the village will grow, strengthening already existing barriers between castes.
Cycleway will not be able to carry the load of tractors, bullock carts and motorcycles, which are already owned by several families within the village. These modes of transport will be confined to poor quality roads. The amount of produce able to be carried by these modes is significantly greater than that of bicycles, and so, the cycleway does not completely support commuting requirements.

When the cycleway is in place there is no way to monitor who uses it. If villagers who own heavy vehicles such as tractors choose to use this facility, increased loads on the track may cause structural failure and extra maintenance costs. Despite the provision of public toilets at regular intervals along the path open defecation may still be an issue, brought about by those who choose to be impatient. To be counteracted, extra cleaning costs may incur, as well as the requirements for an additional educational program which teaches the problems associated with open defecation.
During the construction phase of the cycle way scheme it is critical that there is quality assurance of infrastructure in order for the path to last for its expected design life. The economic sustainability of this project relies upon the minimization of expensive maintenance activities, especially if economic responsibility for the network is transferred to the state government in the future.

It is advised that the cycleway is constructed in 100m sections to have more control over the curing of the concrete while allowing the simultaneous construction of multiple sections. The optional capping layer of the existing subgrade is recommended to provide a stable foundation for the granular sub-base and concrete pavement. A mobile concrete batching plant is recommended so the concrete can be mixed in large quantities on site. Particular care should be taken in ensuring the concrete mix is ideal for local conditions and of consistent thickness, strength and durability. Covering the path with locally available wet paddy straw will keep it damp- allowing the concrete to cure slowly, increasing strength and hardness. The concrete would need to be covered approximately for 2 weeks with light traffic 24 hours after (Pandey, 2006). The transverse contraction joints are to be cut to a depth of 25-33mm within a short time window: after the concrete is strong enough to both support the sawing equipment and prevent raveling during saw operations and before shrinking cracking can occur (Pavement Interactive, 2009). There is a short window of time for the cuts to be made shown in Figure 12 The cut needs to be made after the concrete is strong enough to both support the sawing equipment and to prevent raveling during saw operations and before shrinking cracking can occur (Pavement Interactive, 2009).
A hot-pour liquid sealant should be used to seal the cut to minimise water and incompressible material entering the joint (Pavement Interactive, 2009). A smooth concrete surface isn’t suitable for outdoors, so the surface will need to be brushed with a stiff-bristled broom before it dries. Covering the path with wet paddy straw will keep it damp allowing the concrete to dry slowly (curing) which will make it harder and stronger and utilize locally available materials. The concrete would need to be covered approximately for 2 weeks with light traffic 24 hours after (Pandey, 2006).

The following are a list of testing that need to be undertaken prior to the construction of the cycleway.

- To ensure adequate soil compaction is achieved a geotechnical engineering report will need to be conducted to determine the soil density and degree of compaction needed.
- Testing the concrete for the saw cutting window for the transverse contraction joints.
• Concrete curing would need to be tested to determine the suggested curing times to provide maximum strength and hardness.

A suggested local company to take on the construction of the bike paths is Valecha Engineering Limited, an India-based company responsible for constructing roads, expressways and highways. Valecha was selected to take on this project because of its technical capacity for the construction of 'concrete paved' roadways and its attitude towards environmental protection. Valecha "optimize the use of raw materials and prevent their wastages to the maximum extent by improving and auditing the construction processes at corporate and project levels" (Valecha Engineering Ltd, 2011). Their main focus areas are the minimisation of air pollution raw material, electricity and fuel usage.

In the operation of the maintenance plan, personnel should undertake periodic checks of infrastructure to identify defects. Community involvement should be encouraged, with local residents assisting maintenance authorities through the notification of problem areas.
Our design project operates under the Engineers Without Borders organisation for the Pitchandikulam Forest Community. Our team sought to implement a system that benefits the Devikulam community economically, socially, environmentally and technologically in the design area of transport. We aspired to meet our initial objectives by setting a design criteria and undertaking a whole of life analysis for our design option. A cycleway will provide a design option that is exceptionally sustainable and practical to the community. The design will have limited impacts to the environment in and around Devikulam and the Pitchandikulam Forest Region. Supplemented by the bike provision program, the design will bring about equitable access to services and positive economic growth with improved mobility between neighbouring villages and regional centre of Pondicherry. The Bicycle maintenance centre will ensure the long-term viability of bicycles as the principle transport mode while the education program will seek to bring about a consensus in cultural perceptions about the importance of sustainable transport.

Overall we believe that our project addresses our initial objectives and recommend our project to the Engineers Without Borders group as a response to the 2011 EWB Challenge by providing a solution to improved transport infrastructure in the region. This solution would require communication and collaboration between Engineers Without Borders, the Indian state and central governments, and communities of the Nadukuppam Panchayat in order to be realized.


Transportation

Bike Culture
• Free/subsidised bikes; build a bike
• t-bar
• paddle bike
• Electric bike

Public Transport System
• Tram system
• Light Rail
• Buses
• Extension of train track
• Carpooling
• Electric vehicles

Diverting monsoon water
• Man-made river
• Diverting water to village
• Turbine system to transport water/generate electricity
• Storage tanks

Algal Biodiesel

Improving Road
• Higher road
• Raised bike track

Cable Line
• Transports produce
• Ski lift
APPENDIX B: GANTT CHART OF METHODOLOGY

EWB Interim Report: Gantt Chart

<table>
<thead>
<tr>
<th>16/02</th>
<th>26/02</th>
<th>8/03</th>
<th>18/03</th>
<th>28/03</th>
<th>7/04</th>
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<tr>
<td>Familiarisation with EWB Project</td>
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<td>Preliminary Literature Search on Project Topic</td>
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<td>Defining Project Scope</td>
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<td>Brainstorming Potential Solutions</td>
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<td>Grading and Final Design Selection</td>
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APPENDIX C: CYCLEWAY & ROAD MAPS
Nadukuppam Panchayat Road Network
Nadukuppam, Villupuram District, Tamil Nadu

Information on this map was updated through a combination of GPS Survey and community mapping. In case of any errors or adjustments please report them to the Panchayathan Office.

Nadukuppam Panchayat - Road Network by Road Condition

<table>
<thead>
<tr>
<th>Road Condition</th>
<th>Length (in km)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Good</td>
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</tr>
<tr>
<td>Fair</td>
<td>2.5</td>
</tr>
<tr>
<td>Hay</td>
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</table>

Roads surveyed by GPS survey: November 2009

Map created and produced by Panchayathan Office.
## APPENDIX D: CALCULATIONS

### Calculation for Pessimistic Maintenance Scenario

<table>
<thead>
<tr>
<th>Asphalt surfaced – granular base</th>
<th>Concrete - unreinforced</th>
</tr>
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<tbody>
<tr>
<td><strong>Initial cost $16.61/m²</strong></td>
<td><strong>Initial cost $35.34/m²</strong></td>
</tr>
</tbody>
</table>

#### Maintenance/rehabilitation scenario

**Year 3:** crack sealing over 30%

**Year 6:** asphalt regulate 5%, geotextile seal

**Year 10:** patching of severe shape loss areas 5% of area

**Year 13:** patching 5%, regulation 50%, geotextile seal

**Year 20:** reconstruction of pavement

**Year 23:** crack sealing over 30%

**Year 26:** asphalt regulate 5%, geotextile seal

**Year 30:** patching of severe shape loss areas 5% of area

**Year 33:** patching 5%, regulation 50%, geotextile seal

**Year 40:** patching 5%, regulation 50%, geotextile seal

---

#### Net Present Value

**Year 0 (2000):** construct pavement

$16.61/m²

**Year 3:** crack sealing over 30%

$(1.06)^{-3} \times 2 \times 0.3 = $0.50/m²$

**Year 6:** regulate 5%, place geotextile seal

$(1.06)^{-6} \times (12 \times 0.05 + 6) = $4.65/m²$

**Year 10:** patching of severe shape loss areas 5% of area

$(1.06)^{-10} \times 12 \times 0.05 = $0.34/m²$

**Year 13:** patching 5%, regulation 50%, geotextile Seal

$(1.06)^{-13} \times (12 \times 0.05 + 6 \times 0.5 + 6) = $4.50/m²$

**Year 20:** reconstruction/rehabilitation of pavement

$44 \times (1.06)^{-20}/m²$

**Year 23:** regulate 5%, place geotextile seal

$(1.06)^{-23} \times (12 \times 0.05 + 6) = $1.72/m²$

**Year 26:** patching of severe shape loss areas 5% of area

$(1.06)^{-26} \times 12 \times 0.05 = $0.13/m²$

---

**Year 0:** construct pavement

$35.34/m²$

**Year 5:** joint resealing 1 per 50 m

$(1.06)^{-5} \times 5 \times 0.02 = $0.08/m²$

**Year 10:** slab replacement 2%, joint grinding 1 in 36 m, resealing 1 per 50 m

$(1.06)^{-10} \times (60 \times 0.02 + 10 \times 0.06 + 5 \times 0.02) = $1.06/m²$

**Year 15:** slab replacement 2%, joint grinding 1 in 36 m, resealing 1 per 50 m

$(1.06)^{-15} \times (60 \times 0.05 + 10 \times 0.06 + 5 \times 0.02) = $1.54/m²$

**Year 20:** slab replacement 5%, joint grinding 1 in 24 m, resealing 1 per 50 m

$(1.06)^{-20} \times (60 \times 0.05 + 10 \times 0.04 + 5 \times 0.02) = $1.09/m²$

**Year 25:** slab replacement 5%, joint grinding 1 in 24 m, resealing 1 per 50 m

$(1.06)^{-25} \times (60 \times 0.05 + 10 \times 0.04 + 5 \times 0.02) = $0.82/m²$

**Year 30:** slab replacement 5%, joint grinding 1 in 24 m, resealing 1 per 50 m

$(1.06)^{-30} \times (60 \times 0.05 + 10 \times 0.04 + 5 \times 0.02) = $0.61/m²$

**Year 35:** slab replacement 5%, joint grinding 1 in 24 m, resealing 1 per 50 m

$(1.06)^{-35} \times (60 \times 0.05 + 10 \times 0.04 + 5 \times 0.02) = $0.46/m²$

**Year 40:** slab replacement 5%, joint grinding 1 in 24 m, resealing 1 per 50 m
<table>
<thead>
<tr>
<th>Year</th>
<th>Required Maintenance</th>
<th>Cost $/m² (ARRB 2006)</th>
</tr>
</thead>
<tbody>
<tr>
<td>5</td>
<td>Slab replacement 0.2% of area</td>
<td>0.2</td>
</tr>
<tr>
<td>15</td>
<td>Slab replacement 0.2% of area</td>
<td>0.2</td>
</tr>
<tr>
<td>20</td>
<td>Joint sealant replacement</td>
<td>5</td>
</tr>
<tr>
<td>30</td>
<td>Slab replacement 0.5% of area</td>
<td>0.5</td>
</tr>
<tr>
<td></td>
<td><strong>Total Present Cost of Maintenance Schedule</strong></td>
<td><strong>1.88</strong></td>
</tr>
</tbody>
</table>

1. Present Value of Maintenance = \(0.2(1 + 0.06)^{-5} + 0.2(1 + 0.06)^{-15} + 5(1 + 0.06)^{-20} + 0.5(1 + 0.06)^{-30}\) = $1.88/m²

2. Present Value of Construction = $35.34/m²

3. Total Present Cost = $35.34 + $1.88 = $37.22/m²

4. For 20km of 3m-wide concrete cycle path, Total Cost = $37.22/m² x (20 000 x 3) m² = $2,233,200