INNOVATION IN THE ROAD CONSTRUCTION SECTOR AND ITS BENEFITS TO THE INDUSTRY

Pardeep Kumar Oad

Bachelor of Engineering (Civil)

Diploma in Modern Construction Management

Submitted In Fulfilment of the Requirements for the Degree of

Master of Engineering (Research)

School of Civil Engineering and Built Environment

Science and Engineering Faculty

Queensland University of Technology

2016

Keywords

Innovation; road sector; construction industry; solar roads; material; pavement, technologies; benefits; barriers; drivers

Abstract

It is undeniable that the road construction industry every day is looking for a greater effectiveness and efficiency in its techniques and methods. However, change in the construction environment is not willingly embraced by the construction industry and this conflict to change compromises innovation performance, and unenthusiastically impacts customer and industry goals. In other words, with rising globalisation, roads have become a very vital infrastructure in enabling the transfer of freight as well as people, making the better and sustainable development of roads very important.

Innovation in road construction offers important industry and community benefits. This refers to the use of better materials for the purpose of road construction, such as solar roads, eco-frendly roads, recycled materials, foamed bitumen etc. It can be technology innovation that includes the usage of better technologies for the integration of successful innovation in this sector. Advanced technology includes the automated computerised systems of traffic indicators, having better databases, use of solar road technology or process innovation that can be implemented in this sector, including the use of better engineering practices, more harmony between the private and the public sectors, and employing better quality control in processes by the use of techniques such as Six Sigma. Moreover, there is high government spending in road construction as well as maintenance, so there is also a need for the use of innovation to find methods that will be cost effective. Also, environmental concerns around reduction in the emission of greenhouse gases and reduction in pollution encourage the use of innovation for the adoption of greener methods of road construction as well as maintenance.

The aims of this thesis are to identify and review the use of innovative practices internationally in the road construction sector, through different case studies from different countries, and to explore the suitability of the practices under several road conditions. The data has been collected from case studies from different developed countries and this method of collecting data enables the study of various cases depicting the use of innovation in real life, giving clear indications regarding the importance of innnovation in the road construction industry.

The study result indicates that most developed countries are aware of the need for innovation as the key to sustainable and environment-friendly, cost-effective methods of road construction as well as maintenance. For example, many developed countries such as U.S.A, UK, Germany, Australia etc., have recently used a new, innovative technique developed by Chong et al. (2008), which is an indication of the developed countries' response towards road innovation needs. The study result also indicates that there is a development of the use of recycled materials for road construction, which reveals that there, for example, is the use of recycled printer cartridges to replace road building materials in most developed countries. Innovative practices are being implementing globally in various nations; it is the policy of Hamburg, Germany and the UK to build roads of recycled materials, and implement the use of solar roads and plastic roads. These practices indicate that there is a need for all countries move more towards green methods of road construction to address primary environmental issues such as global warming and climate change.

Table of Contents

List of Figures

List of Tables

Acronyms

AASHTO	American Association of State Highway and Transportation Officials
ABS	Australian Bureau of Statistics
ACI	American Concrete Institute
ASTM	American Society for Testing and Materials
BRITE	Building Research, Innovation, Technology and Environment
CGA	Commonwealth Government of Australia
C.I.S.A.C	C.I.S. Assessment Committee
CRC	The Cooperative Research Centres or Construction Innovation
CTR	Centre for Transportation Research
EME	Enrobes à module élevé (known as high modulus asphalt)
FBS	Foamed Bitumen Stabilisation
FBSP	Foamed bitumen stabilised pavements
FGD	Flue gas desulfurisation
IRVIN	Intelligent Road Vehicle Test Infrastructure
ICT	Information and Communication Technology
ITS	Intelligent Transportation System
NICTA	National ICT Australia
NSW	New South Wales
OECD	Organisation for Economic Co-operation and Development
PCC	Portland Cement Concrete
PPCP	Precast Pre-Stressed Concrete Pavement

PV	Photovoltaic
RAP	Recycled asphalt pavement
R & D	Research and Development
RTA	Road and Traffic Authority of NSW
SCATS	Sydney Coordinated Adaptive Traffic System
SME	Small and medium-sized enterprises
U.S	United State
USEPA	United States Environmental Protection Agency
UW	University of Washington
V2I	Vehicle to Infrastructure
V2V	Vehicle to vehicle
WHO	World Health Organisation
QUT	Queensland University of Technology

Preface

During my Master by Research Degree candidature, one paper on this thesis has been published in a refereed conference proceeding and one paper is expected to be submitted soon to an international journal. The papers are as follows:

Accepted paper

- Oad, P. K., Kumar, A., & Kajewski, S. (2016). *Innovative Technologies in road sector*. 8th International Conference on Maintenance and Rehabilitation of Pavements (MAIREPAV8), Singapore. doi:10.3850/978-981-11-0449-7-136-cd

Working paper

- Oad, P. K., Kumar, A., & Kajewski, S. Innovation in road construction industry: Case studies from developed countries.

Statement of Original Authorship

The work contained in this thesis has not been previously submitted to meet requirements for an award at this or any other higher education institution. To the best of my knowledge and belief, the thesis contains no material previously published or written by another person except where due reference is made.

QUT Verified Signature

Signature:

Date: 25-Nov-2016

Acknowledgements

I would like to express my deepest gratitude to my principal supervisor, Professor Arun Kumar, for all of his valuable advice and enthusiastic support. Professor Kumar, you established an intimate and friendly relationship with me throughout this journey and this gave me the incentive to prove to you my abilities and eagerness to improve my knowledge and skills. You always pushed me beyond my comfort zone and uncovered abilities I never knew I had. Thank you for believing in me, for your patience and support. I am truly grateful also, to my Associate Supervisor, Professor Stephen Kajewski, who provided me with great suggestions and truly valuable feedback. I really appreciate your encouragement, understanding, and support.

I am also grateful to my brothers (Gulshan and Dr Partab), friends, colleagues and other staff in the Department of Civil Engineering and Built Environment for their continuing help, support and guidance, making my university life more enjoyable.

Finally, I express my sincere gratitude to my parents for all their prayers and blessings. Dear Mom (Meeran) and Dad (Basant), this journey would not have been started without your advice and encouragement and the journey would have been very hard to continue and accomplish without your support. Thank you for everything and for giving me a family of whom to be proud.

I would like to express dearest appreciation to my wife (Pooja) for her patience, understanding, and support throughout the course of this study and research work.

Chapter 1 : Introduction

Innovation is identified as a very crucial part of the continued growth and development in the construction industry (Manley, 2006; Slaughter, 1998). Innovation in the road construction sector is very beneficial, as it is certain to bring better results, like better-performing roads with lower adverse environmental impacts and lowered costs and improved quality that would require low maintenance. It has been seen that the adoption of innovative technologies has brought about benefits such as increased share in the market, as well as a better competitive position in the market (Gambatese & Hallowell, 2011a, 2011b). In this research, we would look into the adoption of innovative methods in the road construction sector to gain better outcomes that can be visibly seen and easily measured in terms of reduction of costs of maintenance and road rehabilitation and better performance.

There have been many recent structural changes introduced in the construction industry in recent times (Sexton & Barrett, 2003). The changing trend in the construction sector is making it more customer oriented, adopting innovation to gain competitive advantage (Davies et al., 2003). The changes in the sector are making innovation criteria of strategic importance. It can be seen that road construction sector is also not untouched by these changes and is responding to the demand of adoption and management of conscious innovation (Ling, 2003). Innovation management constitutes the integration of ideas in order to lead to the efficient implementation of novel ideas to result in market solutions causing effectiveness (Drejer, 2002).

The road construction sector is majorly involved in the product innovation (Manley, 2008) that includes the production of concrete of high quality, asphalts, the polymer of re-enforced fiber etc. In this thesis, the cases of road construction and maintenance in developed and developing countries will be studied to understand the benefits of these innovative practices in the roads construction sector.

This chapter is an outline of the background as well as the context of this study about innovation in the road construction sector. It also describes the objectives of this study, as well as the significance of this study and an outline of the course of the entire thesis.

1.1 Present perspective

Innovation in the road development and construction sector is very important, owing to the needs of cutting down the heavy costs incurred in maintaining and building road networks in Australia and also the environmental and economic benefits of road innovation. The road industry of countries such as France, Germany and Australia, is showing relatively poor performance in comparison to the road industry of the rest of the world and there are issues relating to productivity and client satisfaction in this industry (Australian Bureau of Statistics, 2012). The study suggests that the only method to espouse turnaround strategies for the road construction industry of Australia is the implementation of innovative practices and methods of production.

In Australia, road travel plays a very crucial role, although in modern times, many modern means of communication and travel have emerged; still, the importance of road travel cannot be underestimated. For example, about 90% of passenger travel and about 20% of transport of freight happen through the aid of road transportation (Australian Bureau of Statistics, 2012). Finally, the road development of every country needs to consider the social, economic and political considerations of past decades. The demands of the road network have changed with changing social consideration, increasing the demand of an acceptable and innovative road network system (Caerteling et al., 2011).

1.2 RESEARCH AIMS AND OBJECTIVES

The aim of this research is the identification of innovative practices that are currently used in the road construction industry as well as the benefits that this innovation in the road industry affords to business, environment, society, and economy.

The objectives of this research are to

- Study the process of innovation in road construction in different countries around the world
- Determine the factors and the drivers that lead to the acceptance and implementation of innovation in the road construction industry
- Study the processes that are adopted by the road construction sector in order to study the benefits that arise from the adoption of innovation in construction, taking the example of some recent road innovation projects as case studies.

- Analyse the summary of the best innovative practices that are used in the road construction sector, such as innovative materials that are recently being used, new methods of construction, road maintenance and operation.

1.3 RESEARCH SIGNIFICANCE

The practice of constructing road and maintenance is fundamentally efficient and lean, therefore, in this age of environmental management and conservation, the inherent sustainability of present practices of road construction is being extended and to produce diversity of ecologically sustainable options. This research investigates the current innovative practices in the sector of road construction and their benefits to the road construction industry and the transportation system as well as the public.

This research contributes to the establishment of innovation as a potential tool for making the transport system better and management of cost, time as well as infrastructure requirements for building and maintaining roads. This thesis also contributes to the findings of the already practiced methods that can minimise traffic delay, costs, accidents and minimise the use of non-renewable sources in the construction of roads, by replacing them with alternatives that are efficient and environment-friendly.

1.4. STRUCTURE OF THE THESIS

This section provides an overview of the thesis.

- Chapter 1 – Introduction. The first part of the thesis is the introduction, stating the background of the research problem that deals with both the historical as well as present-day state of the road construction industry of Australia, for better identification of gaps. Also, the first chapter discusses the aims and objectives of the study, the limitations and the significance of the research.
- Chapter 2 – Literature Review. This chapter is a comprehensive overview of the existing literature about road construction and innovation in the sector. It enables a clear understanding of the meaning of innovation, innovative practices currently being used and the state of road construction of different developed countries around the globe.
- Chapter 3 – Research Design. This chapter determines the objectives of this proposed research, the importance of this research, the research methods as well as

methodology, and the types of research that have been used in this research. The chapter also gives an outline regarding the course of this study and the method of its implementation.

- Chapter 4 - Innovation. This chapter discusses innovation in road construction in detail: what is innovation and its issues, the role of innovation in the construction industry, drivers of innovation, inhibitors, and barriers to innovation, techniques in road surface products, innovation strategies, and innovation in the Australian road construction industry.
- Chapter 5 - Case Studies. This chapter discusses ten different case studies from different developed countries: case studies in road construction innovation such as the use of recycled material for road construction, eco-friendly innovation for road solutions, solar roads, glow-in-the-dark, precast pre-stressed concrete pavement and technologies used in road innovation.
- Chapter 6 - Analysis and discussion. This chapter describes the analysis result of each selected case study and discusses what benefits can be derived from these case studies for the Australian road construction industry.
- Chapter 7 - Conclusions and implications: This chapter concludes and evaluates the work of the thesis. It also outlines the remaining challenges in the discipline and implications of this work.

Chapter 2 : Literature Review

2.1 INTRODUCTION

In this section, the existing literature relevant to the topic of research has been reviewed. During the literature review process, several resources, such as journal articles, articles in news reports, theses, websites etc. have been examined. The objective-wise literature analysis is done in this chapter to gain a better insight to the research problem.

There have been many recent structural changes introduced in the construction industry in recent times (Sexton & Barrett, 2003). The changing trend in the construction sector is making it more customer oriented, adopting innovation to gain competitive advantage (Davies et al., 2003). The changes in the sector are making innovation criteria of strategic importance. It can be seen that road construction sector is also not untouched by these changes and is responding to the demand of adoption and management of conscious innovation (Ling, 2003). Innovation management constitutes the integration of ideas in order to lead to the efficient implementation of novel ideas to result in market solutions causing effectiveness (Drejer, 2002).

Innovation is identified as a very crucial part of the continued growth and development in the construction industry (Manley, 2006; Slaughter, 1998). Innovation in the road construction sector is very beneficial, as it is certain to bring better results, like better-performing roads with lower adverse environmental impacts and lowered costs and improved quality that would require low maintenance. It has been seen that the adoption of innovative technologies has brought about benefits such as increased share in the market, as well as a better competitive position in the market (Gambatese & Hallowell, 2011a, 2011b). In this research, we would look into the adoption of innovative methods in the road construction sector to gain better outcomes that can be visibly seen and easily measured in terms of reduction of costs of maintenance and road rehabilitation and better performance.

The road construction sector is majorly involved in the product innovation (Manley, 2008) that includes the production of concrete of high quality, asphalts, the polymer of re-enforced fiber etc. In this thesis, the cases of road construction and maintenance in developed and developing countries will be studied to understand the benefits of these innovative practices in the roads construction sector.

Even though there has been a significant innovation in the road construction sector, still the road construction industry lacks a substantial amount of research in the innovation and technology field (Caerteling et al., 2011). There is a still a need to stress the use of innovation for enhancement of the performance of roads in the global forefront as the infrastructure of the roads is very important for contributing to economic and social development by being an effective medium of inflow and outflow of freight, and personal as well as business travel (Kaare & Koppel, 2012).

Although there has been much significant research in the road construction sector, still the diffusion of the product and process innovation in this sector is slow. Also, the provision of liability and risk testing of any new product or process is another issue that the road authorities face. As the construction industry deals with production that has been short – lived, perception is that the innovation process is depressed in this industry in relative comparison to other industries (Manley & McFallan, 2003).

The Prime Minister of Australia John Howard in 2001 said that innovation includes the integration of fresh ideas and transforms resources with an enhanced capacity of wealth generation. These ideas of innovation can enhance all aspects of life (Commonwealth Government of Australia, 2001).

Innovation can be defined as a process that includes improvement on a continuous basis resulting in new or improved product, services, and practices. Innovation can be of two types: technological and organisational. Road innovation is a technological innovation which involves the application of either scientific and engineering concepts.

2.2 BACKGROUND OF INNOVATION IN ROAD SECTOR

In earlier times, road building was done without much planning. Roads were built according to increasing needs, following the tracks that were made by teams of bullock carts and drays. For example, the first Australian road that was built was from the Dawes Battery to the residence of Governor Phillip and ran at a distance of two kilometres. After the settlement of the Parramatta district, a road from the district to Sydney was constructed. The year 1792 marked the building of roads to link the settlements of the Windsor district to Parramatta and Sydney. This road system quickly expanded, but there was no regulation in the early street system of Australia (Australian Bureau of Statistics, 2012).

In the 18th century there was rapid deterioration in the road conditions all over the world. In most of the developed countries, the methods of construction of roads were improving with time as new and innovative technologies were used. The topography of the UK was not very supportive of building roads easily, but the Romans seemed to have little difficulty in building very straight early roads (Rose & Manley, 2012).

In Australia, Governor Macquarie showed commitment and efforts to improve the conditions of the Australian roads in the year 1810. There was a plan to make the roads of Sydney ornamental and regular. Government funds, public subscriptions, and tolls were levied for the construction and the maintenance of Australian roads. Private operators were given the toll collection rights in Australia. In the 19th century, with the introduction of the railways, roads became the secondary transport mode for the transportation of heavy freight (Australian Bureau of Statistics, 2012).

Even in the late 19th century, the road travel of some developed countries was a slow and uncomfortable journey. In Australia, the roads outside country towns were unsealed and crushed metal was used for road construction, which was costly. But in the city, innovative and better methods of road construction were developed and widely used. Sydney was the initiator of wood block pavements in Australia in the 1880swhich were laid in King Street, Sydney, as an experiment (Australian Bureau of Statistics, 2012).

At the end of the decade, many pavements of materials such as black butt, tallow wood, blue gum and red gum were being used in many developed countries. Tar macadam was discovered as an innovative and advanced method of building long-lasting roads in Adelaide, Australia, and Sheffield, UK after tar was tipped over the road as an accident (Caerteling, Di Benedetto, Dorée, Halman, & Song, 2011).

The year 1890 marked an important point in the use of innovation in building the roads when asphalt was used for road building. The 1900s marked innovative road building after attention was paid to the technical aspects of road building. The use of macadamised pavements was started. The roads that had heavy traffic were built by the use of a Telford base and a macadam surface that was water bound. The earlier gravel roads were narrow and for motor mobility they were rough. The solid rubber or steel-rimmed tyres damaged the irregular roadways. The alignment of the roads and the grade and the surface were not fit for heavier vehicles. The Second World War (1939-45) brought many strategic considerations that positively influenced the road networks. This led to the adoption of a system of development of arterial roads in order to support the heavy traffic such as tanks and large trucks. After the war, there was a system of state-aided development and tourist roads, which began to improve the conditions of the roads. The Australian road system moved forward with accelerated growth and innovation.

The road construction sector of Australia

The state and the local government of Australia are responsible for maintaining and the construction of roads. About $15.8 billion in the public roads budget is allocated for maintenance and road renewal. The spending on the core road maintenance program by the NSW and Traffic Authority (RTA) in the year 2010/2011 was $1billion. Thus, we can see that a major amount of public funding is allocated for the maintenance and the renewal of Australian roads. This makes a sustainable and economical innovative road development strategy important and beneficial for Australia, both in terms of environmental and economic benefits.

Australia has adopted competitive contracting for road maintenance; this strategy has resulted in around 10-40% cost savings on road development and maintenance. This strategy has also encouraged the integration of innovation and better services, as shown in Figure 2-1.

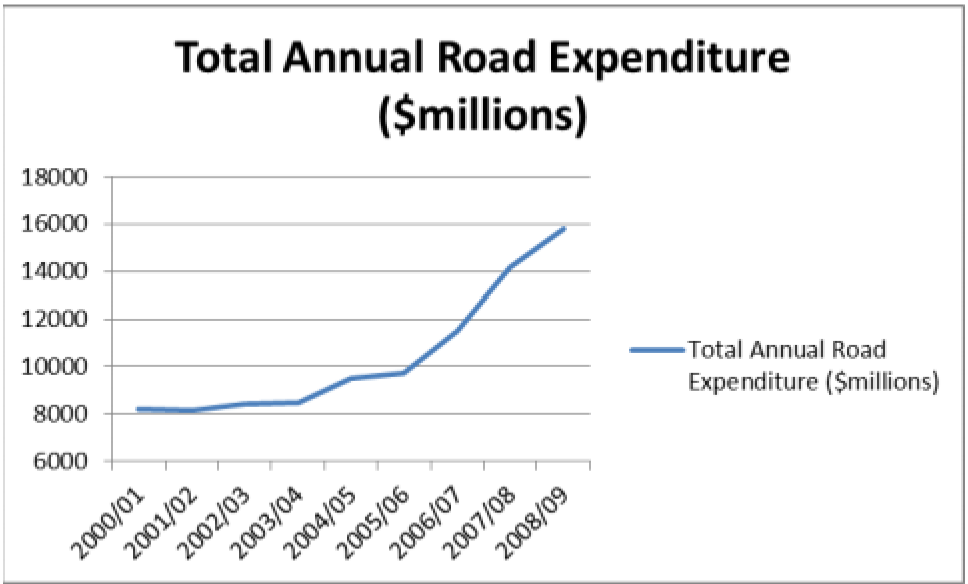


Figure 2-1: Annual road-related expenses-Survey (Dwyer, 2011)

The transport sector contributes to over 23% of the total emission of carbon dioxide from the combustion of fossil fuels. This sector also contributes to a total of 15% emission of greenhouse gases (Australian Bureau of Statistics, 2013). There is a prediction that these emissions will increase by a level of almost 2/3 in the coming thirty years that makes the adoption of innovative strategies to reduce the levels of emissions from the road construction sector imperative.

<u>Road Network of Australia'</u>

The road network of Australia comprises over more than 800,000 kilometres; 18,700 kilometres are of National Highway and 260,000 kilometres include State Roads.

2.3. LITERATURE REVIEW AS PER RESEARCH OBJECTIVES

2.3.1 Objective 1: Determining the factors/drivers leading to the need of innovation

<u>Need for innovation in the road construction:</u> The road construction industry of Australia is being researched from the perspective of innovation and use of advanced technology (Caerteling et al., 2011)**.** There is a growing need for the road construction sector to get due attention to perform better and adopt innovation owing to the fact that the road construction sector in Australia is the main contributor of employment in the nation and the GDP (Caerteling et al., 2011)**.** The infrastructure of roads is very important, as it is the source of transport of freight and ensures business and personal travel mobility (Kaare & Koppel, 2012)**.** The investment required in road construction is much higher in comparison to other small building projects, so with heavy stakes, there is a need to involve planning and research in this industry in order to promote innovation in a proper way (Kaare & Koppel, 2012). There is a growing need to adopt innovation in the road construction of Australia as the adoption of innovation in Australian road construction can serve as a good example for the road network of other countries as well. This is because the construction industry of Australia is involved in more research and development projects than the construction industry of any other nation (Australian Bureau of Statistics, 2013). Although in Australia there is a steady rate of research regarding the product innovation of road construction, the rate of adoption of innovation in the road sector in actual practice is seen as low. This is because in Australia, there is the presence of obstacles in the diffusion of innovation (Rose & Manley, 2012).

The projects of road infrastructure are accountable for the huge investment of the public as this renders services for a long duration. The roads provide services and convenience to people over many generations, so there is a need to assess future development as well as the easy transport of goods and services by roads. To build global connectivity there is a need to adopt innovation as the key that would enable expedition of the process of better road construction.

In recent times, owing to a growing population and globalisation, there has been a high increase in the traffic volume as well as the axle loads on the roads, leading to aggravating issues such as damages to vehicles, congestion, pollution in the air and noise pollution. These are issues that are growing at a very fast rate, raising concerns for the safety of the masses and the ecosystem. Thus there is a need to initiate as well as adopt changes, to make the roads able to meet the needs of the traffic that is growing, as well as making road travel more comfortable and safe. The adoption of innovation through the use of the latest technologies, materials, and processes in the construction of roads is sure to enhance the efficiency of the road construction process and lead to a great reduction in time, as well as cost to the sector of road construction and maintenance.

There is a growing need to find durable as well as reliable infrastructure that can be of use at economical rates. Innovation would lead to lowering the maintenance costs of the road construction sector.

There is also a great need for development of a sustainable system of transport. Sustainable transport can be defined as a system that has developed patterns of travel, meeting the needs of transport with efficiency and at the same time reducing harmful impacts as well as the extra costs incurred (Whiteing & Stantchev, 2008).

There is increased pressure on the road construction authorities to reduce the emissions caused as a result of road construction projects in order to meet the emission targets prescribed by the government. The nuclear disaster in Japan in the year 2011 marked the awareness of many countries to adopt plans and policies to decrease the usage of the nuclear power, such as Germany and Italy. As the government alone cannot achieve the targetted reduction in emissions, there is a growing need for the involvement of the infrastructure sector to enable a reduction in emissions. There is a growing need to find durable as well as reliable infrastructure that can be of use at economical rates. Innovation would lead to lowering the maintenance costs of the road construction sector.

This is because of the following factors.

- Infrastructure greatly contributes to greenhouse gases emission.
- Infrastructure has a major role to play in bringing about a reduction in the emission of greenhouse gases at zero cost by the use of the technology and innovation that are available in the current times.
- Infrastructure at present is the largest employer that has potential to create high demand for green employment.

Owing to the above factors, there is a high demand and need to attain sustainable innovative practices in the infrastructure sector.

There is a need to adopt innovation in the development of road infrastructure because in the near future, the challenges in road development and maintenance are going to increase. This will be owing to the increase and expansion of the world economy and the changes in the weather due to global warming, causing extremes of climatic conditions. These aspects will make road management tougher and the challenges can be overcome by the use of innovation and better technology. There are growing opportunities to transform the road development and construction mechanisms. This would enable society to be better equipped to deal with the changes in climate, leading to a reduction in environmental pressures. The governments of Queensland and Western Australia have shown concern about the better development of roads. There is a need to adopt sustainable strategies for the reduction of greenhouse gases and the costs of road construction and maintenance.

Innovation in road construction leads to the development of techniques and alliance within the stakeholders of the project, that in turn leads to the development of a solid platform assisting the resolution of possible issues in a contract.

The implementation of advanced technologies allow the delivery of better outcomes in terms of cost effectiveness and innovation in the quality of better roads and their construction methods.

Innovation in the road construction sector will bring about the involvement of all designers in the various phases of the construction of roads and lead to better project alliance. This will result in the production of better infrastructure, meeting requirements regarding road safety and quality.

Innovation also brings about better management in the construction industry, which is fundamental to assuring quality and delivering value for money to the end users.

Successful innovation can be attained if collaboration exists between the parties that are the stakeholders, such as industry, government, and the academic community. Investing capital in the field of research and development in the road construction industry can cause better economic benefits by lowering the costs of maintenance of roads due to road damages. Also, innovation in the road construction sector involves fine tuning of advanced technology that suits the application and testing of opportunities in real situations. The countries that are willing to invest in innovation in the road construction sector can reap substantial benefits over time, as this will lead to involvement in the process of knowledge networking and the creation of an insurance policy to safeguard against future uncertainties.

Innovation in the road construction sector is needed as it helps to contribute to the following:

Building of better relationship with the key players

The use of innovation leads to the free flow of technical support involving the external players and their expertise in the creation of a complementary knowledge base. Innovation cannot be successful without the involvement of the various stakeholders in the road construction sector, resulting in the formation of a robust alliance with the manufacturers and the suppliers of the road construction industry and their involvement in the various programs of research and development that involve the better practices and production methods in the field of road construction and maintenance. This will enable the formation of better and more cooperative approaches to delivering projects . This can be illustrated by the example of the East West Link, which has been divided into two parts by the Linking Melbourne Authority:

The Eastern Section that includes the region between the Eastern Freeway and the Port and the Western Section that includes the region in between the Port and the Metropolitan Ring Road. This division has contributed to better management and control between the stakeholders (C.I.S. Assessment Committee, 2014).

Streamlining activities

With the aid of innovation in the road construction sector, there can be an adoption of integrated construction approaches, which will increase the number of small players in the industry.

Innovation can also bring about increased dissemination of knowledge and development of better industry relationships that may minimise the disadvantages of production being an industry having a temporary coalition.

Growing of a better business environment

By having a supportive culture for innovation, the road construction sector in Australia can foster an environment that encourages the sharing of ideas and knowledge and also enhances technical expertise and encourages the risk-taking nature of the industry in Australia (Manley & Blayse, 2004), leading to experimentation and establishment of pilot initiatives to adopt successful road innovation.

Effective client leadership

There is a need for innovation in the Australian road construction sector to achieve effective client leadership; this can be achieved by the maintenance of high level technical competence and having a better pattern of demands . Innovation would promote a pioneering system of procurement in the industry, leading to better alliances and increasing the ability to solve problems specific to the road construction sector. It would also lead to an increase in the setting of performance standards through the betterment of technical expertise and strategies of enforcement (Manley & Blayse, 2004).

Innovation offers a great level of mobility to citizens as well as businesses, protection of the environment and minimisation of wastage of energy and protects the commuters. It should aim to protect people as well as increase the mobility of road transport, making it sustainable. Innovation would enable better international connectivity and exchange of innovative ideas internationally to adopt sustainable innovations in the sector of road transport.

Improving lifestyle, safety, and productivity

It is very important for the infrastructure of any nation to keep the national highway in better condition. However, these road construction sites are a danger zone, as heavy equipment and other vehicles that pass pose a threat to the safety of construction workers. There are many cases of fatal injuries at sites of road construction across the globe. In the USA, Pittsburgh Volvo Construction Equipment, Pennsylvania, is highly aware of the safety of their workers and is working in partnership with the Integrated Innovation Institute at Carnegie Mellon University in order to lead to the usage of technologies in a safer manner so as to reduce the incidence of accident at road construction sites.

Roads that are well planned and of high quality do not just link people and destinations, but also enable improvement in lifestyle as well as safety and productivity. The total annual fatality rate of people on the roads globally accounts for over 1.2 million, and over 50 million people are the victims of road accidents leading to injuries that are not fatal in nature (World Health Organization, 2009)**.** The measures indicate that adopting innovation measures ensuring road safety can cause a significant drop in the rate of accidents and ensure a lower rate of annual deaths. Australia is a city that has a large number of people commuting by bicycle; the country commonly provides facilities for cyclists at the intersections of roads and at traffic signals. Much research to date has not been included to indicate the effectiveness of providing for cycles, but a research study by Turner et al. (2009) shows that the safety benefits increase to around 10% by the installation of lanes for cyclists; also, features in the roads such as flush medians also increase safety, having been found to reduce the rate of accidents (ASTM, 2011)**.**

2.3.2 Objective 2: Process of implement innovation successfully

Some of the innovations that can be of benefit in the road sector are:

The usage of noise-reducing asphalt – the director Western Canada Asphalt, Paving and Construction Product Lines, Jim Bird, says that using asphalt for reduction of traffic noise is a much more efficient process than the use of wall barriers for lowering noise levels. Lafarge has made a product known as Durawhisper, which is effective in the reduction of traffic noise and confirms to all the specification of hot-mix asphalt. It can conveniently be used even in residential areas for construction of roads (Radison, 2013).

Manufacturing by the use of eco-friendly methods - the green technology focus is leading to the development of mixtures of asphalt that do not adversely impact the environment to a great extent. The Duraclime mixture of Lafarge is a product that conforms to all specifications of hot mix. The manufacturing process of the Duraclime employs lower temperature to reduce the smell, fuel consumption and emissions, making it environment-friendly. This product is known to lower the carbon footprint by 20% and is almost equally priced when compared to hot-mix asphalt.

Using ingredients that are eco-friendly – the use of ingredients that are eco-friendly is another innovative method of road construction. There have been instances of using materials that are recycled in the mix. For an example, Vegecol is a mix produced by the Canadian Road Builders Inc., which is made of completely renewable materials that are plant-based. This mix can be used both for major roads and for walking and biking pavements too. In the Vegecol, there is no petrochemical added, which leads to less contamination of runoff water.

Use of computer modelling – there can be innovation in road building and manufacture by the use of computer modelling methods too. By the use of computer modelling, better design of the structures and the construction of the roadways that are highly performing can be made possible. It enables immediate testing of ideas and impacts (Davies et al., 2003). IRVIN (Intelligent Road Vehicle Test Infrastructure) is one of the popular tools that is used to test and assess the ITS solutions regarding traffic congestion, safety criteria, and problems in the environment that can affect road traffic in the initial design phase and process. IRVIN is actually a modular tool allowing the use of combinations of tools to answer any sort of road-related issue that arises (Bakker, Hogema, Huiskamp, & Papp, 2005).

There is a rise in the use of vehicle-to-vehicle (V2V) as well as vehicle-to-infrastructure (V2I) technologies to enable a great range of applications, such as information as well as entertainment, enabling browsing of the web cooperative driving in the times of peak traffic leading to safety of the road commuters etc. With a predicted increase in traffic jams in the future, it is evident that there will be an increase in emissions as well as consumption of natural resources, also increasing the number of the road accidents and the mortality rate of people. According to the World Health Organisation and the World Bank, if appropriate actions are not taken, road injuries are certain to increase, making this the third major contributor of global ailments. V2V, and V2I-enabled networking together are known as V2X networking; this is one of the major discoveries in the field of reducing the number of accidents that happen due to injuries on the road. V2V enables communication in between the vehicles on the road, such as cars, truck, and bikes, without the inclusion of a central controlling unit so there is no requirement of the cellular systems that are traditionally being used. The V2V technologies that are being used currently are based on the Wireless Local Area Network (Ström, Hartenstein, Santi, & Wiesbeck, 2010).

Using pavements that are water saving – these pavements are made by the use of porous asphalt or by using concrete that is pervious. These paved surfaces that are water saving enable the draining of storm water into a catchment area that is below the surface. This material is ideal for building roads in parking lots as it enables people to collect and store runoff water and use it for irrigation purposes. The use of porous asphalt enables the filtration of sediments making it treated and fit for the use of irrigation (Kaare & Koppel, 2012).

The use of perpetual pavements – these pavements last for around 50 years, quite a lot longer than the 20 year expected duration of conventional pavements. These pavements are highly durable as they use asphalts of superior performance and quality. These pavements can model as well as analyse the road systems before they are constructed.

The first perpetual pavement was constructed by Uzarowski in the Red Hill Valley Parkway, Hamilton, in Canada (Radison, 2013). The pavement has a rich mix as its bottom layer is specially designed in the manner of packing with asphalt cement, which cannot be destroyed thus making it crack resistant. The top and the middle layers of this pavement are made by using Super-pave asphalt mixes that are high-quality asphalt. These are resistant to rutting, cracking and wear and tear (Drejer, 2002).

Using reclamation of full-depth – the traditional process of road repair is done by the removal of the asphalt layer that is old and then hauling it for the process of disposal. By full-depth reclamation, road repair can take place by mixing the layer of the old asphalt with the gravel that is underlying. This process leads to the formation of a new combination of asphalt and gravel leading to the formation of a new road base. This is a base material of superior quality. This method has cost benefits and also implications for the environment, posed by the removal of the old asphalt layers causing a reduction in the aggregation amount (Radison, 2013). The American Transportation Vision and Strategy for the 21^{ST} century explains the actions that are required in order to achieve sustainable transport (AASHTO, 2004).

Collaboration – this is a method which enables the joining of all the groups of road builders, transportation authorities, industry partners, government and engineers, to collaborate and share knowledge and information about the best road construction and innovation practices. This is a desirable phenomenon as it leads to the transfer of superior ideas and technologies to build better roads and adopt better road building techniques, leading to the adoption of shared practices to build more innovative roads and better products (Radison, 2013).

The American Transportation Vision and Strategy for the 21ST century explains the actions that are required in order to achieve sustainable transport (AASHTO, 2004).

- There is a need to reduce the atmospheric carbon content and induce energy conservation
- Coordination of the usage of land and support for transportation in order to achieve the objectives of a sustainable system of transport development
- Achievement of better outcomes for communities as well as the environment
- Application of innovative as well as better practices that enable the development as well as the delivery of the projects of transport
- Adoption of a triple bottom line method in order to advance and set standards for achieving the innovation aims as well as the system of transportation performances and policies (AASHTO, 2004)

The collaborative approach of the Washington State Department of Transport also identifies certain green goals for innovation in the road construction sector. They are:

- Implementation of projects and use of technologies that can lead to the reduction of greenhouse gases
- Improvement in the efficiency of fuel and the reduction of the dependence on the sources of energy that are non-renewable in nature
- Reduction in the total energy usage by developing roads and infrastructure that are self- sustainable in nature
- Reduction in the pollution of air and land as well as water (University of Washington, 2011)

2.3.3 Objective 3: Benefits of the innovation in road construction to society

Innovation always leads to adding value to the users. Innovative roads are environment and user-friendly and have fewer maintenance costs, thus adding value to the users. Innovation is not accepted unless it adds value and cost effectiveness to the user.

Innovative roads can also cause a competitive advantage if the level of innovation exceeds the current state of road construction technology in Australia (Hartmann, 2006). The advantage of innovative roads would be that lowering the maintenance costs of these roads. Innovation is very important in construction industries (Hamdani, 2000); innovation can lead to greater capacity to cope with challenges that the construction industry of Australia faces. Research shows that the adoption of innovative practices in the Australian road sector has a high impact on the improvement of organisational effectiveness, as shown in Figure 2-3.

The study of the Queensland road system has revealed that innovative practices in the road construction system lead to increases in efficiency, clients, cost-effectiveness and technical performance. Innovation increases accuracy, information and knowledge to develop better roads, time, speed and quality of the roads, as shown in Figure 2-2.

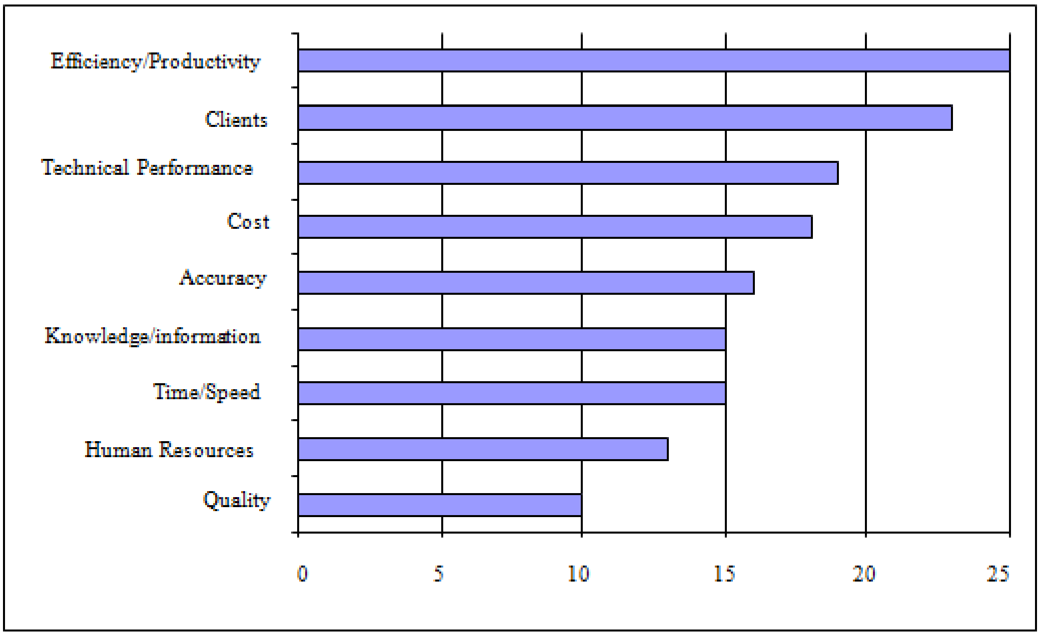


Figure 2-2: Innovative practices in Queensland Road Authority (Austroads, 2014)

It is very important to consider the environmental impacts that the method of road construction will have, because roads have a direct relation to infrastructure and society. There is also a need to meet the challenges of sustainable and environment-friendly road development through the use of innovation and creativity. There is a need to adopt measures to transform the conventional way of the conception and the construction of roads in such a manner that climatic and environmental pressures are reduced. Roads support the existence of lots of allied industries such as the automobile industry, which is a major employer of the Australian economy. Roads support all vehicles that run on the Australian road system and are the cause of the combustion of around 310,000 barrels of oil. This also results in the emission of around 17% of the total greenhouse gases. So, indirectly, roads threaten climatic stability around the globe. Also, roads impact the ecology and agricultural aspects by affecting the ecology and thereby modifying the flora and fauna. Roads are also known as the chief source of all economic activities. By improving road transport, an increase of around 6% of economic growth around the world can be achieved. There is a need to increase the positive economic impacts of roads and at the same time adopt measures to decrease the negative environmental and societal impacts of them by the adoption of creativity and innovation to build roads that are economically safer.

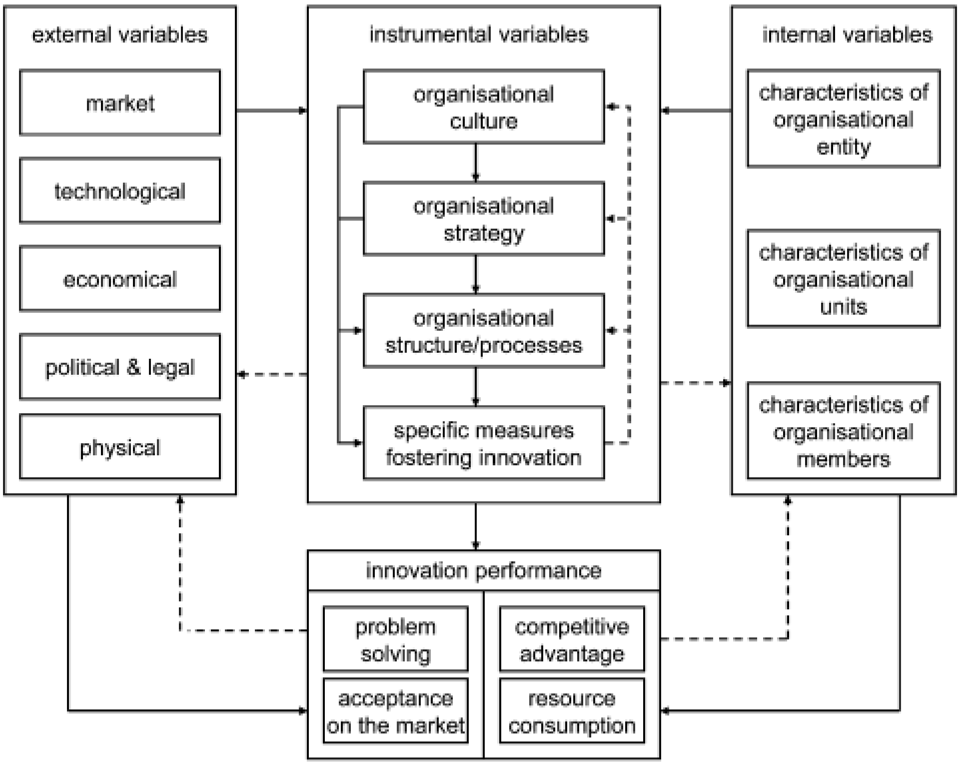


Figure 2-3: Framework for innovation management (Hartmann, 2006)

One kilometer of road construction requires materials such as rock, concrete, asphalt and steel that need to be collected and transported to the site of construction. Road raw materials are the most mined products in the world. The requirement of a two-lane bitumen road can be around 25,000 tons of bitumen, leading to heavy mining activities and earthworks and transportation. This again makes the road one of the greatest reasons for global climate change. Conventional road construction methods can increase the climate change impact and so there is an increasing pressure on the Australian road construction system to work on building more sustainable road construction practices. The Australian government suggests that temperature changes and rainfall, coupled with high migration and the growth of population, can increase the cost of the maintenance of roads by 30% by the year 2100.

The use of innovative ideas that enable the generation of energy from the roadways as well as highways (such as Sola Roads and E Turbine Highways discussed in the Case Study section) can lead to the production of additional output of energy that is needed to meet the requirements of household energy as well as businesses. This would lead to the creation of roads that are self - sufficient in nature as well as benefitting society in terms of meeting the energy requirements of households and businesses in a greener way.

Environment-Friendly Roads

With the increase in the resource consciousness of the mindset of the people, the rise of the need for technologies that are environment-friendly has also increased (Probst et al., 2013). Australia too faces its own environmental issues, such as the depletion of the resources and climatic changes. So the strategy for sustainable road construction needs to be a key strategy for the road construction network of Australia (Wilson, 2011). For achieving this strategy, the current system of transportation is not very sustainable.

The reliance on road infrastructure is a great cost and a great imbalance to the equilibrium of the earth. There is an increasing stress on making the roads greener and environment-friendly. One such sustainable road construction method is solar roadways. In these roads, the asphalt and concrete are replaced by panels that are generated by electricity. Also even in the future, manure may be used, instead of the pavement materials that are used for constructing roads currently. There is a need to have standards set, guiding the use of materials for constructing roads in Australia, similar to the Green States Building Council for road building in the United States. There is much argument about the road contractors being responsible for the bad environmental status of roads. There is a need to conduct a life cycle analysis of the recycled products that can be used for the construction of a road that is environment-friendly (Wilson, 2011).

There can be three alternatives of using new materials for road construction by recycled materials:

- Hot-in-place recycling
- Cold-in-place recycling
- Full Depth Reclamation (Wilson, 2011)

According to the Asphalt Recycling and Reclaiming Association, hot in-place recycling is a method that can be practised on site and in place and it helps in the rehabilitation of the asphalt that is deteriorated, therefore reducing the further use of non-renewable materials for road repair. Thus, the method has both economic as well as environment benefits. The hot-in-place method is one of the most researched methods out of the three listed above. Hadi Dowlatabadi, who is an environmental scientist at the University of British Columbia, has credited the method with causing many environmental and economic benefits. He also researched that the hot-in-place method can lead to the reduction of usage of materials by over 80% and the cost of material cost by a further 80%. North Carolina has adopted hot-in-place recycling leading to having the lowest per square kilometre cost for construction of roads globally (Wilson, 2011).

There is a need to consider the developments of forest roads that are environment-friendly in Australia. There is a need for planning and road construction that are eco-friendly in nature. In the Australian ecosystem, the forest network of roads is necessary for the introduction of practices that are sustainable in nature. If the forest roads are not planned carefully, it can lead to erosion of the majority of the soil. Greater than 90% of the soil erosion is reported from the harvesting of timber in the tropical regions, which is caused by the roads. Therefore, there is a need to integrate proper planning regarding the location of roads and follow innovation to decrease the harmful effects of soil erosion by the roads. There is a need to integrate innovation and proper planning about the locations of the roads so that the clearing of the roadside can be restricted; this would lead to reduction in the earthwork for the preparation of surfaces for road running and also the excavations that are done in order to cut and till slopes.

With modern technology and innovation, there has been the discovery of an efficient system of road surveys by the aid of instruments that are handheld and used in this regard, such as clinometer, altimeter and compass that can be used for getting better economic results. With the use of innovative construction techniques and the use of hydraulic excavators, there can be the construction of roads that are environment-friendly.

There is also a need to stress the necessity of a proper drainage facility of the roads in the forest region as with the drainage system being poorly planned the chances of soil erosion are the highest. The drainage system of the forest roads needs to be planned in a manner that the surface and subsurface water drains off efficiently. Use of innovative road construction methods such as porous asphalt can be helpful in this regard. Therefore, the road construction industry can use the integration of open top culverts made of materials that can easily be sourced, made of combining logs and timbers for road drainage.

The concerns for climate change are growing, leading to energy security and the attempts of conservation of natural resources. All these have led to an increase in the environmental regulations and there is a need to adopt a system of a sustainable method of road construction. There is a need to have corporate social responsibility initiatives, to develop and apply novel technologies that can led to a reduction in the harmful impacts of road construction on the environment, and also a need to adopt innovation for the reduction of adverse environmental impacts and improvement in energy efficiency (Probst et al., 2013).

Chapter 3 : Research Design

3.1 INTRODUCTION

Research is defined as a systematic search for a new happening and the compilation of information that is useful regarding a topic. . In this thesis, research is integrated in order to investigate, as well as find solutions, regarding the adoption of innovation in the sector of road construction. Case studies were selected on the bases of following: 1) cases study must discuss innovation in the road construction industry; 2) the address recent issue in the road construction industry; 3) case study discuss solution of proposed problem. In this chapter the objectives of the current study, the importance of this study, the research methods as well as methodology, and the type of research that will be used are determined. This chapter gives an outline regarding the course of this study and the method of its implementation (Rajasekar, Philominathan, & Chinnathambi, 2013).

3.2 RESEARCH AIMS AND OBJECTIVES

The aim of this research is the identification of the innovative practices that are currently used in the road construction industry as well as the benefits that this innovation in the road industry affords to business, environment, society and the economy. The detailed aims and objectives of this study are mentioned in Chapter 1 of this thesis.

3.3 HYPOTHESIS FOR RESEARCH

For this current study, the hypothesis is that use of innovation in the road construction sector causes better productivity as well as societal benefits.

3.4 RESEARCH QUESTIONS

This research is oriented towards answering the following research questions.

What is the strategy adopted by developed economies such as Australia, to improve on innovations in the road construction sector and what are the specific problems that these economies encounter in the path of implementation of innovative practices?

What are the benefits of adopting innovation in the road construction sector? What improvements can be brought about in the local and the global environment by road construction innovation in terms of reduction in greenhouse gases, better economic and environmental outcomes and reducing the usage of the non-renewable energy sources?

3.5 TYPE OF RESEARCH

Descriptive Research

Descriptive research is inclusive of surveys as well as findings of facts and enquiries of various types. The main purpose of this type of research is to give a description about the current state of affairs. In the case of business research as well as social sciences, descriptive research is also known as ex post facto research. In this type of research, the researcher has little or no control over the variables; only what has already happened can be reported. This is a very appropriate kind of research for the scenario of studying innovative practices in the field of road construction as it is feasible and the best direction in which to report the current innovative successful practices and their impact in the sector of road construction, which the developed economies such as road construction industry can test and implement. As this research in the true sense is very technical in nature, descriptive research gives an in-depth information as well as an indication of the state and the impacts of the innovative practices that are being followed in the sector of road construction.

Analytical research

In this type of research the facts as well as the information that is already available are analysed in order to be able to critically evaluate the material. This study will also incorporate the analytical type of research in analysing the current innovative practices that are used successfully globally. This would enable an understanding of the best practices in the field of road construction as well as their impact on the productivity as well as increased efficiency of the construction sector as well as a benefit to the economy.

3.6 RESEARCH METHODOLOGY

The research in this thesis is based on twelve different case studies. Case studies are a very good method of understanding a complex subject and also create a deep understanding of the data that is already known, in the form of secondary researchers. In this thesis, the case study method has enabled a deep emphasis of the contextual analysis of innovation in the road construction sector. The case study method is a widely used, popular qualitative analysis technique. According to Robert K. Yin, the case study method is a means of empirical study, enabling the investigation of a phenomenon that is contemporary in nature and includes situations in real life, including a wide application of ideas. This method is used in the case where the distinction between the boundary and the phenomenon is not clear.

3.6.1 What is a case study research

The compelling feature that results in the beginning of all the case study research is the desire to derive a deep understanding of either a single or much small number of cases, in the context of the real world. In this case we would examine a number of cases in order to gain a deep understanding of the global scenario regarding the innovative practices that the road construction sector is using, and the success and the positive impacts of these practices in terms of increase productivity and sustainable road construction that requires little maintenance. Ultimately this leads to cost effectiveness as the burden of road maintenance is very high and is a regular expense that the road construction department and the government have to incur. As a part of the by-product, as well as the main feature in the appreciation of the case study method of research, the case studies that are relevant to the focus of the study are most likely to be taken from many evidence sources and not from the single source of evidence (Baxter & Jack, 2008).

The case study method of research takes place by assuming that the examination of the context, as well as the complex conditions, takes place by the cases that are being covered being an integral part of conducting the research. The case study method of research takes the consideration of studying things further ahead than the research variables. As a part of the by-product, as well as the main feature in the appreciation of the case study method of research, the case studies that are relevant to the focus of the study are most likely to be taken from many evidence sources and not from the single source of evidence.

3.6.2 Uses of case study method

This is a qualitative method of research that enables the exploration of an occurrence or a phenomenon by the use of many sources of data.

The tasks of this research to analyse the current innovative practices that are used in the road construction sector includes the selection of a case study of a successful global innovation in the road construction process, material or method. Collection of the relevant data of the case study is achieved through a host of sources such as journal articles, news feeds, company website etc., analysis of the data that is collected and presentation of the report as well as the results of the case study.

As an analysis of a small number of cases is not sufficient for the establishment of a reliable investigation, there is a need for an intense study of various cases.

There are three situations when the case study method can be used.

The case study method of research can be used when there is the need to answer a question that is descriptive in nature, which explains what has already happened or what is currently happening. If an exploratory question needs to be answered that explains how has something happened. Alternative methods of research can be used for answering other types of questions, such as the effectiveness of an initiative in the production of a particular outcome and the frequency of an occurrence (Baxter & Jack, 2008).

Table 3.1: Methods to check case studies design

Tests	Case Study Tactic	Phase of Research in Which Tactic occurs
Construct validity	• Use multiple sources of evidence • Establish chain of evidence • Have key informants review draft case study report	Data collection Data collection Composition
Internal validity	• Do pattern matching • Do explanation building • Do time series analysis • Do logic models	Data analysis Data analysis Data analysis Data analysis
External validity	• Use rival theories within single cases • Use replication logic in multiple case studies	Research design Research design
Reliability	• Use case studies protocol • Develop case study database	Data collection Data collection

Source: Modified from (Yin, 2003, 2009)

If the emphasis of the research is to determine the occurrence of the phenomenon in the context of the real world scenario, by using the case study method, the data can be collected in a setting that is natural, in comparison to relying on the data that is derived in nature, as shown Table 3.1.

Using the questionnaire method can be relevant in the study of other situations, but when there is an instance of the application of field work that is original in nature, the case study method can lead to the creation of the best understanding.

Thirdly, the case study methods are very commonly used these days for the purpose of conducting evaluations. Many evaluation processes have been documented by the use of the case study method of research.

3.6.3 Justification of a case study method

This current study is based on answering descriptive questions that explain the state of the actions that have occurred in the innovation of the road construction sector. This is also a study that is exploratory in nature and requires answering the questions regarding how the innovation has advanced in the sector of the construction of the road and maintenance. This is a real world scenario, so the use of the case study method ensures that innovation in the field of road construction is not explored via just one lens but by the use of many lenses that allow the multi-faceted understanding of the phenomenon that is to be explored as well as investigated, as shown in Table 3.2.

Table 3.2: The case study design (Baxter & Jack, 2008)(Yin, 2003, 2009)

.	Single Case Design	Multiple case Design
Holistic (single unit of analysis)	Type 1	Type 3
Embedded (multiple units of analysis)	Type 2	Type 4

3.6.4 Determination of the cases or the unit of Analysis

As the main aim of this study is to explore cases in order to best describe the innovation methods as well as techniques that are used in the road construction sector, use of many cases are valid and logical. As well as the definitions and the examples of the case studies that are used in this study, the analysis section leads to providing strength and a better understanding of the phenomenon that is being investigated, as shown in Table 3.3.

Table 3.3: Type of case studies that are used in this study

Type of case study	Definition	Methods use in the current research
Explanatory (Yin, 2003)	This is a type of case study that is used if the intention of the researcher is answering a question that is required in order to be able to answer the causal links of the situations that are real life in nature. These real-life interventions are very complex in nature for the purpose of survey as well as experimental strategies (Yin, 2003)	
Exploratory	These are the case studies that are used to describe to intervene phenomena and the real-life context of its occurrence (Yin, 2003)	
Multiple case studies	This method is used to explore the differences between various case studies. The main aim of using this method is the replication of findings between various cases. This type of case study enables the drawing of comparison, leading to a careful choice of cases enabling the researcher to be able to choose cases in order to predict the similarity of the results in all the cases that are chosen for this study. Also, contrasting results in between the cases that are chosen can be predicted by using the case study	This study has adopted the multiple case study method by studying the current innovative practices over many cases such as; • The solar roads (Hruska, 2014) • The glow-in-dark highway of Netherlands (Hruska, 2014) • Current innovative techniques used by the RTA of Australia • Toner recycling for roads (Chong-White, Hengst,

Continued

Table 3.3: continued

	method of research on the basis of a theory (Yin, 2003)	Quail, Glenn Geers, & Goeldner, 2008) • The Jet Stream Super-Highway (Radison, 2013) • Precast Prestressed Concrete Pavement by U.S Department of transportation F.H.A • Use of recycled asphalt for the production of roads in Hamburg Germany • The innovative eco-friendly road solution by Innowattech (Probst et al., 2013)

3.6.5 Use of multiple case studies

As the aim of this study is to investigate the current innovative practices that are followed globally in the sector of road construction, there is a need to integrate the use of many cases over the globe to study the innovation that is successful and is being used and tested in various parts of the world. There is a different context that is answered in each of these cases. Using a collective as well as multiple case studies has enabled the ability to analyse the research questions within each and across each setting. The use of many case studies stating the innovative practices in the road construction has enabled a clear understanding of the technologies and the approaches that have been developed as well as those that developing economies are using, in order to make road construction as well as maintenance better.

Data sources

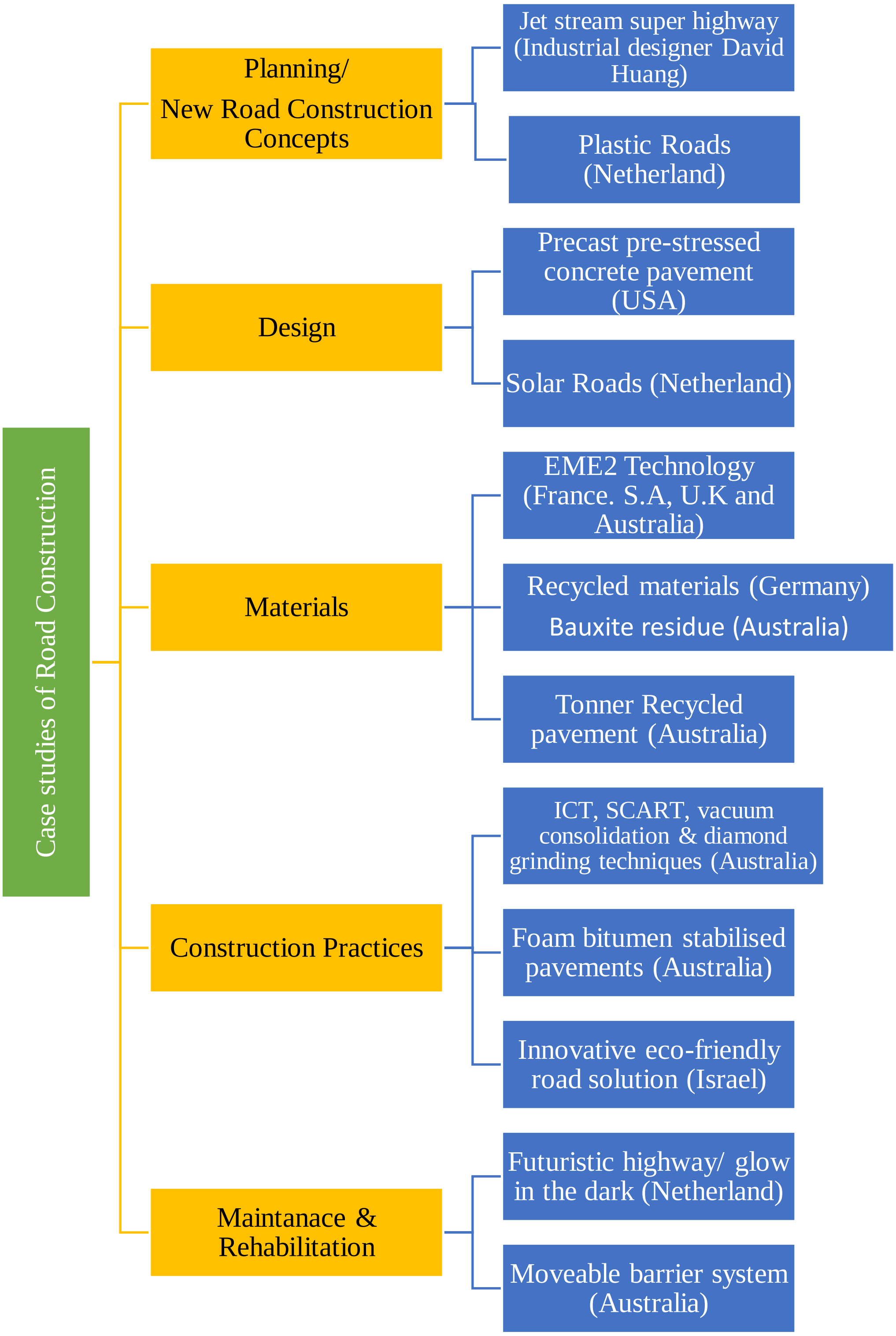
In order to make a substantial finding and analysis, in this study multiple sources of data are being used; the adoption of the strategy of the use of multiple data sources also increases the credibility of the research (Yin, 2003, 2009). The sources of data that are used in this study are documentations, report, conference proceedings, company reports, newspaper articles, journal publications, websites etc. The use of many case studies stating the innovative practices in the road construction has enabled a clear understanding of the technologies and the approaches that have been developed as well as those that developing economies are using, in order to make road construction and maintenance better.

The adoption of the qualitative approach in the case study method of research has enabled the investigator to be able to collect as well as integrate the quantitative approaches and integrate the data of the qualitative survey as well. In the current study, there is the adaptation of the multiple case study method that is investigated and then converged in the analysis section and handled on an individual basis.

3.6.6 Case study analysis

There are five techniques according to Yin, (2009) that can be used for the analysis of the cases: pattern matching, the linking of the data with propositions, building explanations, analysis of the time series, logic models as well as the synthesis of the cross case. In this study all the data that are collected via means of multiple case analysis will be converged in order to create an overall in-depth understanding of the innovative practices that are being used currently and the type of innovation road industry around the world can implement. After the case study documentation section, there is the section for analysis and discussion and then conclusion. This scheme enables easy correlation between the cases in order to be able to reach the purpose of the research as well as the convergence of all the cases that are to be analysed, as shown in Figure **3.1**.

***Figure 3.1*: Flow chart for selected case studies (developed by Pardeep Kumar Oad)**



Chapter 4 : Innovation

4.1 INTRODUCTION

Innovation has been considered as the chief source of economic improvements (Hartmann, 2006). Innovation has been linked to the increased profitability of the economy and is the chief source of improvement outcomes for the environment, especially in the sector of the development of the infrastructure of roads (Commonwealth Government of Australia, 2001). Innovation can take place by the invention of novel technologies or products and services that have not been used before. Also, an unused novel managerial practice can also be termed as innovation. The road industry, which is considered as mature industry innovation, can be regarded as a new system adopted by the organisation but it is not necessary for the practice, product or service to be new to the industry, world or the nation. The innovation is also associated with a substantial amount of benefit.

Innovation can be defined as a way of doing new things or finding better and new ways of doing things that already exist. Innovation can be of two types: product innovation, which involves the creation of better products and services, or process innovation, which includes implementing better ways and methods of the production of goods or delivering services. Innovation can also include the improvement or adoption of a new way of how the organisation and the suppliers interact for the delivery of products and services in the organisation. There can be a difference between the innovation in technology and the innovation in the organisation, and sometimes both can go together. There can also be an incremental innovation, which includes minor changes to the existing products and services. There can be radical innovations too, that include a major change in the organisation of the processes and working of the products. The construction industry can be subjected to all of these kinds of innovation (PREST, 2006).

4.1.1The Definition of Innovation

Despite the fact that there is no specific definition of innovation present in literature, there are many variable definitions that can be found in literature; out of those some are not precise to construction innovation, such as:

- "*Innovation means the application of new knowledge to industry and includes new products, new processes, and social and organisational change" (Firth and Mellor 1999).*

- *"A technological product innovation is the implementation/commercialization of a product with improved performance characteristics such as to deliver objectively new or improved services to the customer. A technological process innovation is the implementation/adoption of new or significantly improved production or delivery methods. It may involve changes in equipment, human resources, working methods or a combination of these" (OECD, 1997).*

On the other hand, a few define construction innovation such as:

- *"Application of technology that is new to an organization and that significantly improves the design and construction of a living space by decreasing installed cost, increasing installed performance, and/or improving the business process" (Toole, 1998);*
  - *"Anything new that is actually used" (Slaughter, 1993);*

  - *"The act of introducing and using new ideas, technologies, products and/or processes aimed at solve problems, viewing things differently, improving efficiency and effectiveness, or enhancing the standard of living" (CERF, 2000).*

Therefore, innovation in the construction field is effective progress and execution of new ideas, products, and procedure, so that organisations can increase performance and efficiency (Barrett, Sexton, & Lee, 2008; Sexton & Barrett, 2003).
Invention and innovation are different, invention means a new idea, which then results in innovation by an innovation process.

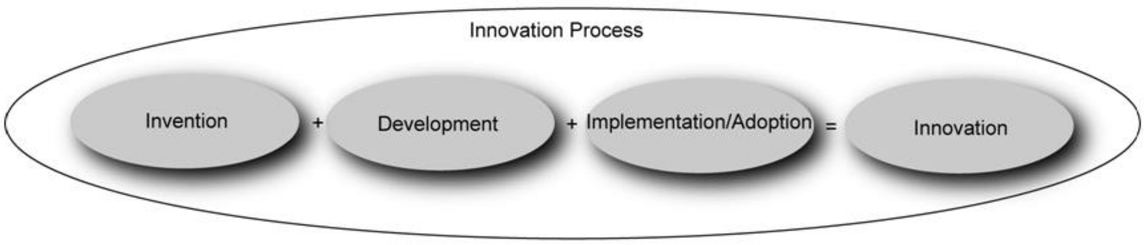


Figure 4-1: Innovation Process (Widén, 2006)

The innovation process comprises of three steps, as shown in Figure 4-1.

- Invention (new idea)
- Development
- Implementation (adoption).

It is not mandatory that innovation needs invention every time; any new idea can be picked from other sources, like other companies or other industry. It is good when an innovative idea turns in to practice. Sometimes, it may not need a new idea; it can be started because of need, problem or if something is missing then a healthier and substitute pathway is used (Brown, Hampson, Brandon, & Pillay, 2008).

4.1.2 Innovation as a critical issue

Better quality of life and future prosperity worldwide depends not only on the business market and natural resources or having skilled labour only, but besides all these important factors, considerable accomplishments have been made in economic growth and community benefit by adopting an innovation. People are living better standards by using new innovation. Mass markets have been created by implementing a new process, and now the products are more assessable. Companies that have more innovative ideas are dynamic and growing more; this is same for countries too.

4.2 INNOVATION IN CONSTRUCTION SECTOR

Any contraction that encompasses new methods of material in construction is defined as innovative construction (Montana Department of Transportation, 2009). The basic means of innovative construction is to minimise the cost, maintenance, increasing life, quality and satisfy clients; it is market driven innovation (Yahya, 2015).

Goodrum et al., 2005, stated that innovation in the highway industry comprises twelve groups: material innovative, innovative field methods, construction technology, innovative management, information technology, contracting innovative, innovative planning and design phase, innovative financing. Further, they classified highway construction into four chief categories.

Highway construction is a fast growing field and that is why it needs new idea and special material and development of new techniques, as discussed before. This industry always needs new material and methods that can reduce capital cost and save time, achieve a diminished stream of traffic and affect and raise safety levels.

1. **Innovative in Planning and Design**

This includes prior allocation facilities before the start of works, creating access strips for utilities, making traffic planes with the association of the transport department to control traffic.

2. **Innovative in Construction Management**

Management innovative includes designation of a single manager to do early planning to the finishing point, presenting new processes for expediting schedules, web-based crew association and practice windowed millstone.

3. **Innovative in Construction Materials and Technology**

Material innovation constitutes using new ingredients like fast curing concrete for pavements, precast components and geosynthetic-reinforced earth platforms for embankments. These pile supported platforms are the most-used innovative material in construction (Goodrum et. al, 2005).

4. **Innovative in Contracting**

In this innovation, organisation creates a team concept, where a design team synchronises direct needs and issues suggested at an early stage. There is increases frequency of coordination and communication between parties.

4.3 DRIVERS OF INNOVATION

There are six factors defined by Blayse and Manley (2004) that can effect innovation in construction.

- clients and manufacturers;
- production structure;
- individual connection with the firm ;
- associations between the industry and external parties;
- procurement organisations protocols/standards; and
- Resource type and quality of an organisation.

Factors affecting innovation depend upon the business goals. If in business, for example, a firm is more towards new technologies and they want to be known for technologies in the market compared to another firm, which is more towards cost only. A survey was done by Manley and McFallan (2002) on an organisation working in the Queensland road and bridge industry; efficiency and productivity were a most significant driver for innovation, and of second-most importance was clients.

Another research study was done in the Dutch construction industry by Bossink (2004). According to this research there are four major kinds of innovation drivers. i-e technological capability, boundary-spanning knowledge exchange, and environmental pressure.

1. A survey on the Australian construction industry called the BRITE project was analysed by Hardie et al. (2006); according to them the main drivers for innovation are productivity/efficiency and client/customer desires. While cost effectiveness was given less importance, they mentioned reducing the time and lowering the cost effect significant to innovation, but they are not the primary drivers.

2. Barrett and Sexton (2006) established research on a small construction company, normally a company that is based on the project. They concluded that the drivers for innovation have three levels; first, the small firm is not always interested in innovation. Second, they describe the hierarchy of motivational drivers. They said that instead of progression being linear, it is dynamic and recurring. Third, once the owner of any small construction firm reached the height of the proprietor’s desire for success, they did not want any further growth in the company.

3. Gambates et al. (2007) conducted research based on interview and an online survey with persons in the construction industry of the USA; in this research they recognised the factors affecting innovation and also method and practice that assist and boost innovation. According to the result of this research, the major factor that drives innovation is cost saving. Besides this, other factors were quality improvement, competitive advantage in the market, growing productivity and safety.

4. Thorpe et al. (2009) conducted research in Queensland, Australia; this research was done around 100 small contractors dealing with residential housing; according to this

research, the main drivers for innovation are meeting customers' demands and efficiency/ output.

Productivity, efficiency, and fulfilling customers' demands are considered the principal drivers for innovation, according to this literature review. On the contrary, the proposition has been made that construction industry is different in the context of innovation compared to other industries. Because this is mainly based on projects, novelty remains hidden when evolved at the project level (Aouad et al., 2010). They added further that innovation is mainly about the process and improving product material. Conversely, Blayse and Manley (2004) acknowledged key elements that could affect innovation in construction i.e. associations between individuals and firms within the business, the association between industry and stockholders, the production structure, procurement standards, and nature of company resource, as shown in Table 4.1. Further drivers of innovation are found in Appendix A.

4.4 INHIBITORS AND BARRIERS OF INNOVATION

There are so many barriers that can be an obstruction for innovation; it is very crucial for an organisation to discover and control those barriers for the superior administration of innovation. There are some studies that have been made on barriers to innovation.

1. A survey was done by Toole (1998) on 100 average-sized construction companies. In that research, the main concern was on motivators and inhibitors for innovation in the residential construction industry. He determined that before implementing any innovation, builders need confirmation of better success rates for that innovation. Therefore, untested new innovation with great insecurity was approved by relying on reliable evidence, for example, subcontractors and other builders. On the other hand, the innovation that is more secure needs less active sources, such as proprietor and architect.

2. Anderson and Schaan (2001) conducted a study on Canadian construction companies. They conducted a survey about hindrances that these companies are facing while adopting innovation, like new construction products, equipment, and new systems. They described that there were three major kinds of barriers to innovation. First, one was a market obstacle; the second obstacle was because of human resources and the last one was the external support service obstacle. Table 4.1 portrays the percentages of obstacles in adopting an innovation.

	Small	Medium	Large	All
Market Obstacles				
High Cost	73%	65%	69%	71%
Lack of client interest	27%	24%	32%	27%
Resistance to change of affiliated businesses	12%	12%	11%	12%
Risk of legal liability	13%	18%	20%	14%
Restrictive codes and standards	20%	29%	36%	22%
Human Resource Obstacles				
Shortage of skilled workers	45%	38%	44%	44%
Lack of in-house expertise	25%	23%	25%	24%
Inability to retrain workers with the required time	16%	21%	18%	16%
Worker resistance to change	20%	26%	32%	21%
External Support Obstacles				
Lack of technical support from vendors	8%	12%	16%	9%
Lack of technical support from consultants	5%	7%	13%	6%
Inability to evaluate new products/equipment	14%	14%	21%	14%

Table 4.1: Innovation barriers (Anderson & Schaan, 2001)

3. Manley and McFallan (2003) established that the most important obstacle to innovation is budget and that was mainly due to staff-associated matters and the conventional nature of investors.
4. In the survey by Ganbates et al. (2007) within companies working in the USA industry, they found different factors that are key innovation barriers.

   Table 4.2 contains the internal and external factors experienced by contributors as major barriers.

Barriers of Innovations	Rating
Not applicable to all projects	41%
Not recognised by clients	40%
Fear of change	36%
Competitive bidding	31%
Low return on investment	27%
Long payback period	26%
Industry regulations and codes	23%
Low investment in R&D	23%
Risk of failure	21%.

Table 4.2: Internal and External barriers in the USA (Gambates et al., 2007)

From this literature, two important conclusions are:

01. Internal innovation barriers can be explored, identified and managed to minimise their negative impacts.

02. External innovation barriers are beyond an organisations' control. However, management can position the organisation to reduce their impact.

Further barriers to innovation are found in Appendix.

4.5 INNOVATIONS AND TECHNIQUES IN ROAD SURFACE PRODUCTS

Owing to the importance of the road network in carrying freight and humans from one destination to another, it is of concern to use innovative technology and concepts for building roads that support environment and transport. It is also necessary to consider cost effectiveness for building roads and maintaining them as road maintenance is a costly affair.

The road industry around the world can implement product innovation measures by using new materials for the construction of roads; these can be the use of concretes and asphalts that are high performance, as well as the use of geosynthetics, composites of polymer that are fibre-reinforced. Also, the road industry can test the use of intelligent technologies of the network, lighting, devices for damping and energy dissipation.

Australia is integrating many innovative road development and management strategies. The Queensland road industry is adopting innovative processes. The top ten technologies used by the Queensland road industry in the year 2002 are email, Computer Network, training budget of staff, Quality certification, Geotextile fabrics, Digital Photography, Websites, Computer- aided design and Computerised project management (Manley & McFallan, 2003).

The road industry around the globe can implement five conceptual characteristics, such as:

- Having adequate organisational resources
- Adopting better procurement systems
- Managing industry relationships
- Overseeing the regulatory conditions
- Having a better structure of production (Rose & Manley, 2014)

The road industry can use the integration of optimisation of the thickness of the pavement to suit the conditions that are anticipated, and efficient allocation of funds and capital. Also, the new practices that need to be adopted include design and performances that adopt efficient material extraction methods and transport, earthwork and efficient paving.

Use of efficient alternatives to the materials in road construction can also lead to the creation of sustainable roads that are environment-friendly and an aid to better societal impacts. By the use of alternative materials for road base there can be a reduction of carbon achieved; also, the design of roads can be done in a way to encourage the transport of people on foot and via cycles, thereby decreasing the emission of pollutants on the environment that are released by the combustion of automobile fuels.

Using Epoxy asphalt

Epoxy asphalt is a compound that is made of epoxy resin and asphalt. This is being used in road construction in airports. This compound is highly stable at hot temperatures.

Use of external force on the roads by the pavement slab method and post-tensioned method

The existence of transverse joints in the roads can cause breakage in the corner and spall leading to deterioration of the roads. The use of external force by the pavement slab method and post-tensioned method can address this issue. The prestressing tendons are usually arranged in a longitudinal form, which would lead to the formation of conventional long post-tensioned concrete pavement or the PTCP. The gaps in the slab lead to the breaking in continuity of the construction of the pavement. This is the part where the highest amount of construction degradation takes place.

4.6 INNOVATIVE STRATEGIES

Innovation in the road development and construction sector is very important, owing to the needs of cutting down the heavy costs incurred in maintaining and building road networks in Australia and also the environmental and economic benefits of road innovation, but there is a need to tackle and overcome certain obstacles and hindrances to the adoption of innovative technologies.

- These can be the high costs of technology implementation
- The limitation of funds
- The stakeholders being conservative and not open to innovation
- Staff and their efficiency-related issues
- Time constraints

- Low volume of available work on road innovation

To a person who lacks training, the surface of the road can just seem like asphalt or concrete layered uniformly, but in the actual sense, roads are made using a variety of products and techniques to ensure the prevention of cracking of the pavements or decreasing the noise of the traffic. Also, innovation in road construction has enabled the adoption of strategies for water conservation. According to Ludomoir Uzarowski, the principal of the Pavement and Materials Engineering of Golder Association Ltd, in present times, there is the availability of advanced technology, thus making road construction more efficient and of higher quality.

4.7 IMPROVEMENT IN ROAD INDUSTRY

According to the study of Manley & Blayse, (2004) innovation has significant benefit in the road development of Australia. Clients have influential roles to act as the drivers of innovation in this road development. Encouragement given to manufacturers and practioners for their participation in research and development activities to better build innovative roads that are sustainable would continue to add value. There is a need to Fostering long-term relationships with clients in the road sector in order to adopt approaches that are more cooperative lead to timely and efficient delivery of the projects (Manley & Blayse, 2004).

Also, the authors suggested that using an original innovation or the use of a technology and practice innovation is equally effective in the road development of Australia. As road building is a contract-based project, so the contract type of a particular road building project plays a determining role in the existence of innovation opportunities, leading to greater benefits. It is equally essential to building strong relationships with the key players involved in building roads, to create a supportive environment for innovation. By the use of brokers that are innovative, there can be the efficient development of technical support and assistance and the knowledge base can be widened.

Chapter 5 : Case Studies

5.1 INTRODUCTION

In this chapter, a variety of innovation that is being practiced across the globe will be assessed. The case studies that have been selected in this research consider the innovation needs and requirements of the road construction industry such as reduction in the emission of greenhouse gases, construction of environment-friendly roads, and using technology as well as materials to lower construction time and the costs incurred. These case studies altogether provide a wholesome view of the innovation that has developed, as well as the developing nations adopting it that have shown better results and outcomes, as shown in Table 5.6. The analysis of the benefits of this innovation and the investigation of the environmental, social, economic and technological impacts enable the justification of the suggestion of using these innovative practices to enable better and sustainable road construction innovation in the Australian context. Many case studies have been investigated in this chapter to enable a clear understanding of the innovative practices that the road construction industry can implement, by using various sources. The case studies regarding the recent innovation in the road construction sector in Australia, such as the innovative practices of the RTA NSW and the use of recycled cartridges from printers being used as road surface material, allow an examination of the current state of innovative practices in the Australian road construction sector. These case studies exemplify awareness in Australia to adopt innovation as a measure to integrate sustainability and efficiency in the road construction sector, but also the need to adopt better practices from other parts of world.

5.2 CASE STUDY -1: USE OF RECYCLED MATERIALS

A). Use of recycled asphalt for the production of roads in Hamburg Germany – this innovation has been used in Hamburg in Germany. In that city, a new policy has been implemented stating that the roads of Hamburg need to be repaired by the use of only recycled materials. Also, there has been a significant increase in the price of materials that were used for the construction of roads, including bitumen and other aggregates. So the city has engaged road construction companies to carry out research and development to provide a sustainable solution to cater for the needs of the new policy, as well as tackle the issues of the increased price of road construction materials. The solution was provided by the use of the 100 % RAP and by stipulating asphalt at low temperatures. This not only leads to less energy usage but also lowers the harmful emissions of gases such as carbon dioxide. Bitumen is one of the most costly products that is used for the construction of roads. Although a mere 5% of the road material composition is bitumen, it contributes to 60% of the costs of road building. Also, bitumen is an oil based product which is not sustainable and cannot be locally sourced, adding to the high price volatility of the material.

A public procurement took place and the tender was restricted, involving only five bidders. STORIMPEX AsphalTec Gmbh was an organisation that was given the tender. Hamburg, by the aid of this project, could save 30% of the costs compared to the conventional costs borne for a project of road resurfacing. Germany developed a cooperative approach to tackling the issue and approached many companies to suggest ways for the removal of recycling and bitumen. The testing of solutions was permitted on the roads of the city and the road construction authority of Hamburg was given the power to test the solutions. With the aid of field testing, a sustainable solution was discovered without negatively affecting the life and the quality of the roads.

The city resorted to a purchasing mechanism that was responsible and led to a business solution that was both sustainable and environment-friendly. This led to the saving of costs and complying with the policy of using recyclable materials for road construction. This project attained greater success owing to the reason that the contractors were approached directly to build a solution. The road development process, by the use of recycled Asphalt, is patented by the organisation STORIMPEX AsphalTec Gmbh. This technique of manufacturing has led to the emergence of an innovative technology leading to a system of cheaper asphalt production with the same durability and quality as the conventionally used method of asphalt production. This method has gained wide acceptance and popularity and many cities of Germany, England and Brazil have adopted this system of production (Innovation Seed, 2012).

B). Using recycled industrial materials in Roadways

The use of industrial materials as a replacement of the non-renewable products that need mining as well as processing has become a very common and abundant phenomenon. This leads to the conservation of natural resources as well as to the reduction in the usage of energy and pollution that is a by-product of mining and producing these materials that are used in the construction of roads.

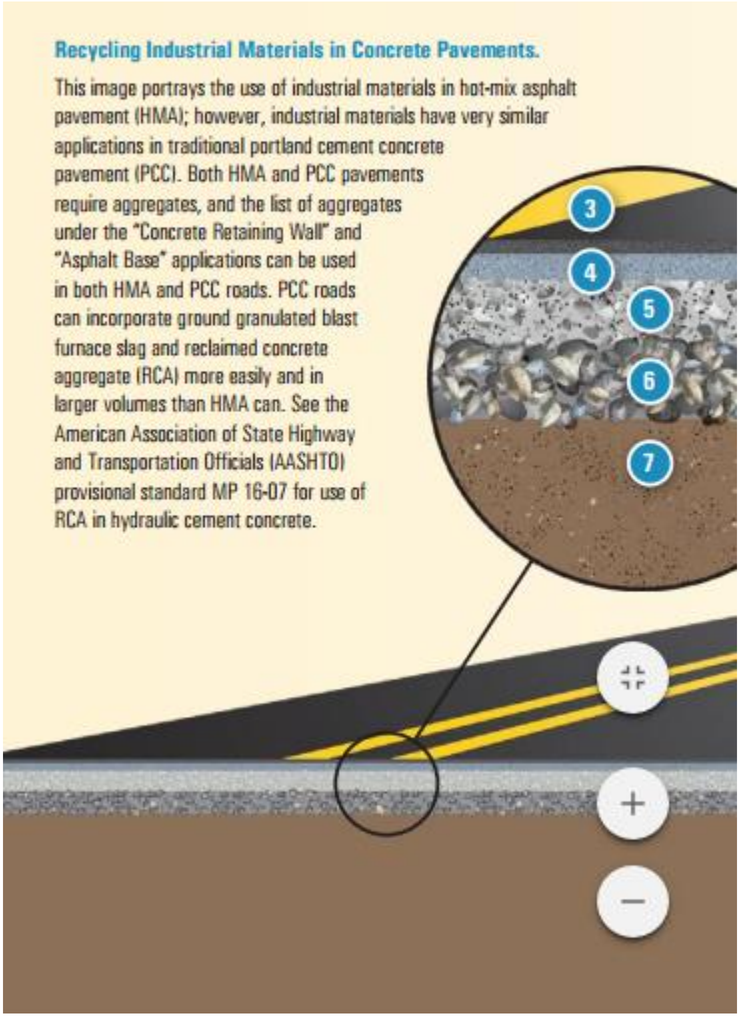


Figure 5-1: The recycled materials used in Concrete Pavements (United States Environmental Protection Agency, 2012)

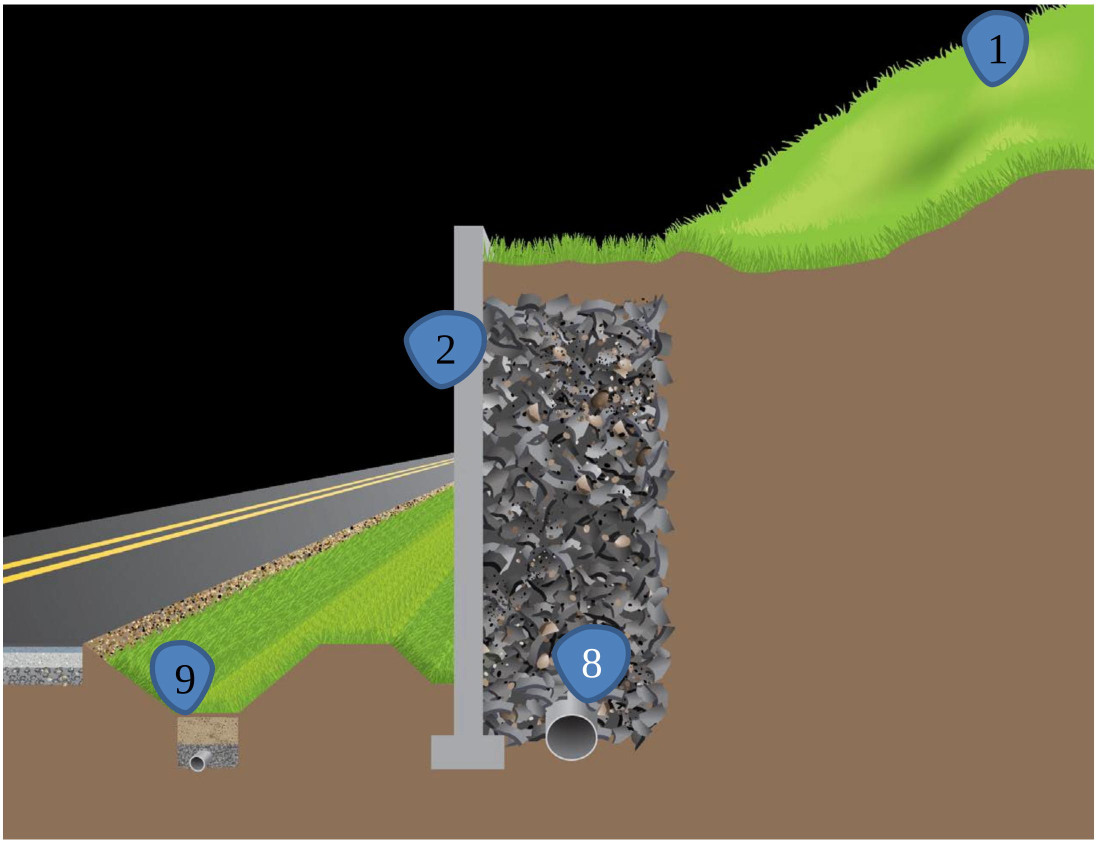


Figure 5-2: Modified: The recycled materials for Concrete Pavements (United States Environmental Protection Agency, 2012)

Pointwise illustration of the use of industrial materials in the construction of roads;

1. Embankment

The topsoil of the embankment of the roads can be replaced by substances such as pulp, paper and other by-products like steel slag, FGD etc. Using these industrial materials can also lead to the improvement in the soil conditions and increase the growth of plants and lead to reduction in the run-off; coal ash is also a very suitable material for the embankment fills.

2. Using Earth Walls that are Mechanically Stabilised

By retaining the walls, the soil as well as the rock salt can be held back; this can prevent the erosion of the slopes along the sides of the roads.

Fly ash, as well as ground granulated from the blast furnaces in the form of slag, can be used as a partial replacement in place of using the Portland cement that enables making the concrete more durable as well as strong.

The bottom ash is used as concrete aggregate, and sands from foundry, concrete that is reclaimed and slag from the blast furnaces can be used.

Portland cement can be made by mixing it with fly ash, FGD, gypsum, sand from foundry, slag, and steel.

3. The surface of Asphalt

The slag from the blast furnaces and from the boilers can be used in place of the virgin aggregates that are used in the surface layer of asphalt.

4. Base layer of Asphalt

The base layer of asphalt can be replaced with bottom ash, sand from the foundry; concrete that is reclaimed mixed with asphalt can be used as an aggregate instead of the base layer of pure asphalt.

The use of rubber tires and roofing shingles can be an addition to hot asphalt and the base mix. This would lead to an increase in flexibility as well as the durability of the pavements and lead to the reduction of the need of the virgin asphalt that is very costly.

5 & 6. The granular base as well as sub base

Many industrial materials can be used in the place of the granular layer of base as well as sub-base that includes:

- The foundry sand
- Glass
- Bottom Ash, slag from blast furnace
- Tyres from scrap

7. Subgrade

This is the layer of the original soil that can be used, in order to improve the structure as well as stability of the subgrade, upon which the road can be built

8. Structural Fill

The role of this layer is to support the retaining walls as well as relieve pressure from them.

The shredded tires that are scrap are best suited for applying as structural fill; being light in weight these tyres can drain easily and lead to resistance from penetration by frost.

9. Vegetated Swale

A vegetated swale, also called a drainage swale or bioswale, is a shallow stormwater channel that is densely planted with a variety of grasses, shrubs, and/or trees designed to slow, filter, and infiltrate stormwater runoff. An environment-friendly method that can provide better drainage to the roadways is by the use of vegetated swales; this can help to improve the quality of water. The scrap tyres, the concrete or asphalt cullet of glass, slag of blast furnaces can be used in the place of traditional material such as virgin gravel or sand.

Table 5.1: The use of industrial waste in road construction industry (Schroeder, 2015)

Waste Material	Annual Rates in Millions of Metric Tons		Current and Past Highway Uses				
	Produced	Recycled Reused	Asphalt Pavement	Concrete Pavement	Base Course	Embankment	Other
Blast Furnace Slag	1	14.1	Accepted use as an aggregate in base and surface (friction) coarse, research indicates good performance	Accepted use as a cement additive in granulated form, research is ongoing	Accepted use, good, hard, durable aggregate	Limited but accepted use,	Research in Roller Compacted concrete accepted as ice control abrasive
Carpet Fibre Wastes	2	14.2	Experimental stages in HMA and SMA no field data	Experimental Stages, no field data	No known use	No known use	No known use
Coal Combustion By-products							
Coal Fly Ash	45	11	Past use as a mineral filler, research ongoing	Accepted use research ongoing	Used in soil stabilisation	Used in flowable fills, embankment	Used in all types of PCC
Coal Bottom Ash or Bottom Slag	16	5	Combined ash as a fine aggregate, performance data limited	Use unknown	Use unknown	Used as a sub-base material, embankment	Lightweight concrete, abrasives
Flue Gas Desulfurisation Waste	18	??	Use unknown	Used as a set retarder	Used with cement in soil stabilisation	Used as an embankment material	No known use
Glass	12.0	2.4	Accepted use, long-term performance research under way	Past research indicated performance problems	Used in dense and open-graded basis	Some research projects under way	Limited use as a painted bead, pipes backfill

Continued

Table 5.1: continued

Mill Tailings	432	<1%	Accepted use, research indicates good performance	Limited but accepted use	Use unknown	Accepted use	Use unknown
Municipal Waste Combustion Ash	7.3	<10%	Past research indicated good performance - Environmental questions	No known use	Used in cement-stabilised bases	Used in soil stabilisation	No known use
Plastic	14.7	0.3	Used as a binder additive	Experimental stage	No known use	No known use	Used as fence or delineator posts, guardrail blackouts
Reclaimed Concrete Pavement	3	??	Limited use, long-term performance research under way	Limited use, research under way	Accepted use	Accepted use	Used as rip-rap
Reclaimed Asphalt Pavement	91	73	Variety of accepted uses	Experimental stages	Accepted use	Accepted use	Used as shoulder material
Roofing Shingle Waste Industry-Produced Re-roofing Waste	0.4 7.7	<1%	Limited use, research under way	No known use	No known use	No known use	Used as a pothole patching material
Scrap Tires	2.3	0.4	Accepted use, extensive research being conducted	Experimental Stages	Used as an insulator	Used with some success - research continuing	Being marketed for use as noise or retaining wall, molded posts, many minor uses
Steel Slag	7.5	6.9	Past research indicates good performance	Extensive research, poor performance	Limited use	Accepted use	Ice control
Waste Rock	954	<1%	Accepted use, research indicates good performance	Limited but accepted use	Use unknown	Use unknown	No known use

The case of San Francisco Bay Bridge Reconstruction

The Bay Bridge of San Francisco was damaged in the earthquake of 1989 and its reconstruction started in 2002. The reconstruction took advantage of using the unique properties of fly ash as well as the granulated ash from the blast furnaces in order to enhance the strength as well as the durability of the concrete that is used. This project used the chemical properties of fly ash concrete in order to cover up the negative effects of the sea water and salt fog that has corrosive action, as the structural requirement of the earthquake zone.

The zone of the bridge that has a high content of salt is made by using a mixture of concrete that contains 50% fly ash that leads to the prevention of cracking after the hardening of the cement. This is a very common occurrence in the areas where the water is salty. The use of the round fly ash particles leads to improvement in the workability of the mixture; the use of fly ash makes the mixture denser as well as stronger than the traditional concrete that is being used, making it better equipped to carry heavy loads. There is the use of over 30 mixes of concrete designs for the construction of the new bridge; some of these mixes are made of more than 50% fly ash. The bridge construction process also used slag that was ground granulated from the blast furnace. This slag was used in the pier column and resulted in the improvement of the durability as well as workability of the bridge (United States Environmental Protection Agency, 2012).

Driving factors for this project

- Cost efficiency as the price of the road surface materials such as bitumen has increased significantly
- Energy conservation and decreasing the amount of emissions of carbon dioxide as well as other harmful gases is another driving factor for this project

Barriers to the project

There is a need to understand and adhere to the waste management techniques and regulations in order to implement this project.

Economic Benefits of using recycled materials

Although bitumen constitutes only 5% of the physical road but it takes up over 60% of the cost of the road construction, this technology saves about 60% of the costs of the road maintenance and construction. The use of this method could save 30% of costs compared to the conventional costs borne for a project of road resurfacing.

Environmental and sustainable benefits

Energy conservation and decreasing the amount of emissions of carbon dioxide as well as other harmful gases is another driving factor for this project. This innovation not only leads to less energy usage but also lowers the harmful emissions of gases such as carbon dioxide. The city resorted to a purchasing mechanism that lead to a business solution that was both sustainable and environment-friendly. This resulted in saving of costs and complying with the policy of using recyclable materials for road construction.

5.3 CASE STUDY 2: THE INNOVATIVE ECO-FRIENDLY ROAD SOLUTION

Early research to build roads concentrated on decreasing the environmental foot-print for construction of new roads through optimising direction arrangement, handling storm-water runoff and regulatory erosion. The case of the roads of Ra'anana and Haifa, Israel, is an example of the extemporary use of innovation for harvesting the waste kinetic energy and using it to generate electricity.

An Israel firm has developed customised piezotech generators that can use the wasted kinetic energy of the roads and transform it into electricity. This technology is being used in road solutions as the kinetic energy that is transformed into electric energy is harvested and used for lighting the roads and road signalling systems. It is also used for lighting the diodes that emit lights (Probst et al., 2013).

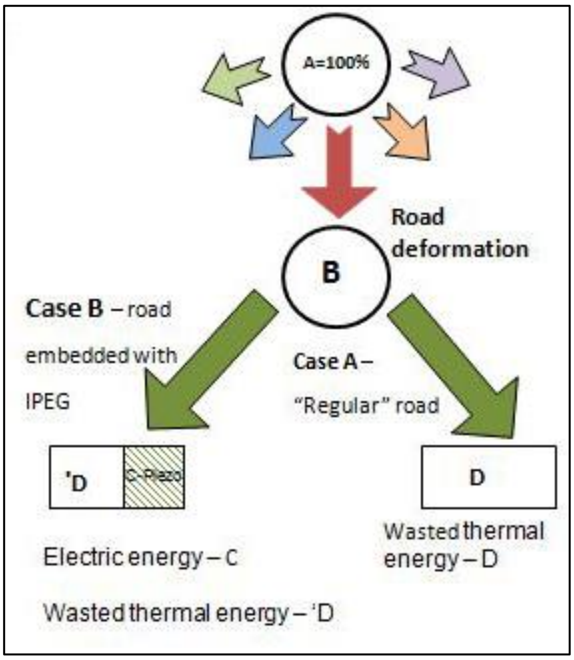


Figure 5-3: Technical information on road innovation industry

There are trials being conducted to test the sustainability of these solutions in the Technion Institute of Technology in Haifa. At this place, a vehicle that has once travelled over the road by the aid of Peizoelectric Electric Generators is planted 6cm underneath the level of the road and is located at a distance of over 30 cm apart. These IPEG in an actual sense are crystals of piezoelectric nature that can use the mechanical energy that is created as a result of any variation in the weight and movement as well as changes in the temperature, and then convert the mechanical energy thus generated into electrical energy. The energy that is harvested thus is then stored in the storage system via capacitors. There are various small projects that are implemented by Innowattech near the highway that is located in the region of Ben Gurion International Airport.

Innowattech proclaims that these IPEGs are very easy to use and not very costly as the installation process is cheap. They are placed in between the layers of the road and are mounted with the help of electronic cards in order to store the electrical energy that is generated by the traffic. Generally, this system is used by covering it with an asphalt layer, but in place of the layer of asphalt, even concrete as well as a composite of concrete can be used. These systems can be installed at the time of the construction of a new road and even during the maintenance of an existing road surface. The benefit of this system is that the cost of installation of these systems is lower than the installation cost of either wind or solar systems.

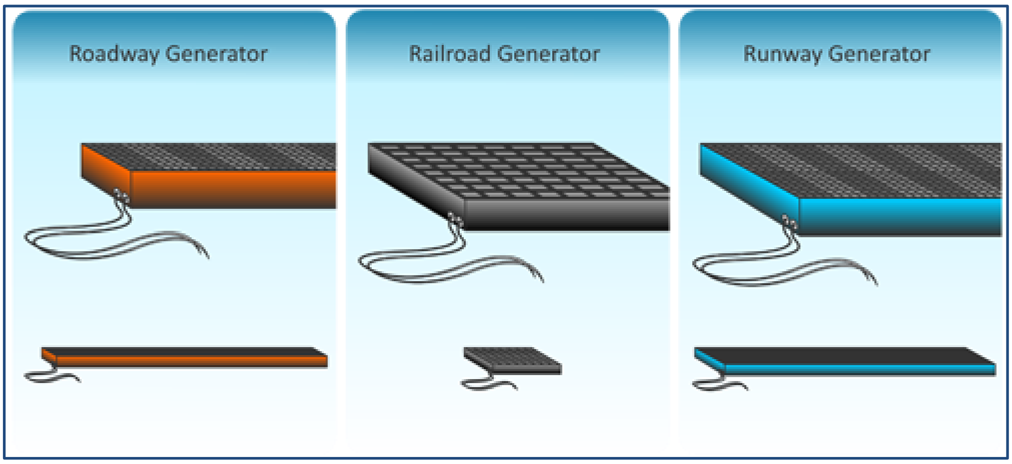


Figure 5-4: Energy harvesting piezoelectric

Economic benefits of using the Technology

This method can reduce the usage of non-renewable sources of energy for the generation of kinetic energy, leading to a tremendous amount of cost saving. It can save up to 80% of energy generation costs and provide employment opportunity, further increasing the economic benefits.

Environment and sustainable benefits

The solution that the Innowattech provides has given many advantages to the road construction system. This has led to the sole reliance of roads on the parasitic energy, as the movement of traffic on roads produces kinetic energy, which is harvested in the form of electric energy. They give a constant supply of electric energy to the roads irrespective of the condition of the weather. This is a system of electric energy to the roads that is proven against any theft and damage. This system has led to the creation of smart roads in the area, leading to self-sufficiency of roads, as they do not depend on the electricity supply of the area for lighting up, thus conservation of energy also is made possible (Probst et al., 2013).

5.4 CASE STUDY 3: SOLAR ROADS

What are solar roads?

These are roads that are constituted of solar panels that are arranged serially and are engineered structurally to drive vehicles upon them. These are revolutionary and innovative alternatives to the roads that are made of asphalt and petroleum bi-products. Also, this is a green alternative to the use of fossil fuel in the generation of electricity. The solar roads are based on the phenomenon of being able to store the maximum amount of energy and then transform it in the form of electric energy. The energy generated can be used to light the roads as well as generate electricity for the commercial areas and the local homes. The main breakthrough of this project is the solar panel that stores energy. The Netherlands is the first country in the world to open a solar bike lane. This path joins Amsterdam with the suburban areas of Krommenie and Wormerveer. This roadway runs at a stretch of 70 metres. This is the first ever solar road which is a bike path that harvests energy and is paved. After six months of the trial period of this solar road, it is said that the solar road system is showing improved performances and better success than what was expected. The road is able to gather around 3,000 kWh electric energy, which is sufficient to illuminate a small house for more than a year. Sten de Wit, who is the spokesman for the road, says that if the annual yield of the SolaRoad is translated, it is expected to generate greater than 70 kWh meter of energy on an annual basis. The idea of constructing solar roads became very popular and there was also talk of making the entire roads of the United States of America lit with the solar panels but, the Netherlands was the first country to actually construct the solar road and is the pioneer in the innovation of solar roads (Macdonald, 2015).

Solar Roads in America

Scott and Julie Brusaw have raised a campaign to raise $ 2 million for constructing a solar roads network.

Solar power still requires a high adoption rate in order to be able to solve the energy requirement but solar roadways are a major step to conserve a high amount of energy. Apart from generation of electricity, these solar roads are fitted with LEDs that give the drivers information, just like the highway signs that are overhead and can be built with heating elements that could be used to melt ice in the seasons of snowfall.

The solar roads were demonstrated on a road to the M1 Toddington motorway service station; this project was granted by the Highway Agency. This is a very innovative system that enables the collection of solar energy in the summer seasons; these are stored in units known as a Thermal Bank and are later used to melt the ice from roads in winter. The system is made up of two solar collectors that are arranged in the form of an array and integrated to the surface of the road. The solar collectors are the orange panels shown in the figure below. This system has two thermal banks also, which are the blue panels in the figure below and have the function to store thermal energy (ICAX, 2015).

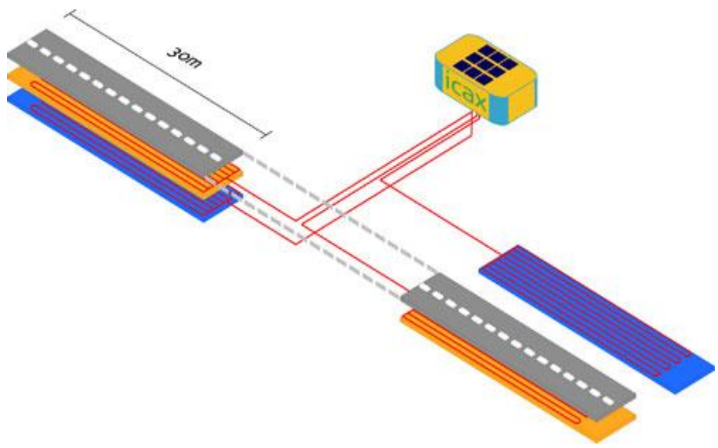


Figure 5-5: The thermal banks of the Solar Panels (ICAX, 2015)

If the overall interstate road system can be replaced with the solar panels of the solar roads, the energy crisis of the entire United State of America could be solved.

"If all the roads in the US were converted to solar roadways, the Solar Roadways website claims, the country would generate three times as much energy as it currently uses and cut greenhouse gases by 75 percent."(The Guardian, 2014)

The road manufacturing material and strength

These solar roads use solar panels that are placed on the path of Dutch bikes. The construction of the road is such that the solar panels are placed in between the silicon rubber, glass, and concrete. These roads are made strong and can support trucks of 12-tonne weight easily, without causing any destruction or damage to the roads. All the solar panels of the road are in turn connected to a smart meter, which causes the optimisation of the output of these roads and increases their energy output, leading to efficient street and traffic lighting or the lighting of the road grid. The durability of the system is a much-researched outcome of five years of research and development by the engineers that are involved in the project. The solar panels are made such that the damage or breakage in a particular solar panel leads to the switching off of that particular PV panel only, whereas the other panels still work efficiently. This is done in order to increase the durability of these roads (Macdonald, 2015).

In the first trial of the SolaRoad there were greater than 150,000 cyclists that participated in the testing by riding their cycles over the road. The road to date is diagnosed of just one flaw; that is, the road has a small coating section for providing additional grip to the vehicles that ride over the surface of these roads. This coating gets delaminated as a result of fluctuations in the temperature. However, the SolaRoad team is working constantly to overcome this flaw of the road. According to Stan Klerks, who is a scientist at the Dutch research group in TNO, the parent company of the SolaRoad, the engineers have come up with efficient coatings that are able to deal with a load of traffic on these roads. The solar panels of these roads are designed in a manner that they let the high amount of light pass through them and have very low maintenance. They are said to last for at least a time span of 20 years (Hruska, 2014).

This new solar road costs around 4.3 Million AUD $. There is a futuristic plan to extend the solar road to a 100 metres lane in the year 2016. There is a plan to use solar energy as a source of electric energy to power the traffic lights and even run electric cars and use solar panels. This project was highly appreciated by the local community, most especially school children and local commuters. An average of 2,000 cycle owners are expected to use the solar road for commuting daily. The Netherlands Organisation for Applied Scientific Research has named this innovative road as SolaRoad. The composition of this solar road is crystalline solar cells, which are layered and made of silicon. These cells are embedded in the pathways of concrete and are then covered with the use of a layer of translucent tempered glass (Hruska, 2014) as shown in Figure 5-6.

Figure 5-6: Pre-fabricated slabs of the solar panel (Hruska, 2014)

Road Surface Layer - this is a translucent layer that is of high strength and it give traction and let sunlight pass through the cells of solar collectors. The surface layer of the roads can handle heavy loads of traffic in the peak traffic hours with the heaviest congestion. The road surface layer is waterproof in nature so that the electronic layer underlying it is protected. The road surface is subjected to a treatment of a coating of the non-adhesive material coating. The construction of the road is done maintaining a slope so as slow the accumulation of dust and dirt and minimise the damage to the solar cells. As there cannot be the adjustment of these solar roads to the direction of the sun's rays, the generation of electric energy from the solar panels of these roads is about 30% less than the solar cells that are placed on the roofs of the house for electric water heating and the power generation process (Katharine, 2014).

Electronic layer - this layer is composed of an array of cells; most of them are composed of a solar collecting cell which has LED's paintings. These cells are composed of super caps that have the role of storing the energy of the sun for usage in future. A Solar Road Panel™ can generate energy by itself and store as well as distribute energy; these panels can heat themselves, leading to the melting of snow as well as the accumulation of ice in the northern climate. So there is no requirement of manual removal of snow and ice from the roads and no need to shut down schools as well as businesses when there are heavy snow falls. There is a communication device on every 12 feet of these panels leading to the building of an intelligent system of highways.

Layer of base plate - the electronic layer leads to the collection and the storage of energy from the sun; the function of the base plate layer is the distribution of the power that is collected by the electronic layer (as well as the signals of data that are collected from the internet and television as well as cellular devices) to homes as well as businesses that are interconnected to these Solar Roadways, for their energy as well as internet data requirements. Each base plate has four sides to which the power, as well as the data signals, is linked. The base plate layer is also waterproof in order to protect the electronic layer that lies above it.

Figure 5-7: Test usage of the Bike Solar Road (Hruska, 2014)

In Amsterdam, there has been laid a 70 metre stretch of cycle road that uses rugged, photovoltaic cells from textured glass. Biking is very popular in Amsterdam, so the road initiative is very popular and effective.

Currently, 70 metres of the initial plan of 100 metres of the solar road is brought to completion. The path is made in a location such that there is consistent sun lighting for the most part of the day. The image above shows the solar road that is located on the left side of the pathway whereas the right side is the traditional concrete road.

In addition to these Solar Roads, the Netherlands is also working on inventing roads that produce power.

Figure 5-8: The Bike Solar Road (Hruska, 2014)

The traction that is used in the solar roads is such that the road is textured and is also bumpy. The road is well textured to give it additional grip, so that slipping from the surface of these solar roads is not possible and is convenient and safer for the bikers. This is in consideration of the maritime climate of Amsterdam, which makes it prone to frequent rainfalls in the winter season, but in Amsterdam snowfall is not very common (Hruska, 2014).

<u>The wear and tear and the reflectance of the solar road</u>

These roads are more reflective in nature than the traditional concrete roads. The Figure 5-9 shows the high reflectance of these solar roads due to the installation of the solar panels. These solar panels are installed on the road used for biking owing to the wear and tear that is expected to occur on it. Studies suggest that the road wear and tear can be indicated by the fourth-power law. This law indicates that the fourth power of the axle weight of a vehicle is proportional to the damage and wear and tear that the vehicle causes to the surface of the road. Although factors such as pressure and speed also relate to the damage that the vehicles cause to the roads, still bikes damage the roads to a much lesser extent than cars and heavy automobiles. This is why there is the construction of a biking road using solar panels, as the magnitude of stress by the bikes to the road surface is much less than that of the cars (Hruska, 2014).

Figure 5-9: High reflectance of the solar road (Hruska, 2014)

The benefits and potential of these roads that use solar energy is huge. They generate a huge amount of energy that is just not sustainable for the road itself, but can also be used to light local households as they generate sufficient amounts of energy, thereby giving excellent opportunities for lighting. Design lab Studio, Roosegaarde, in the Netherlands, set up a solar road in the Netherlands. This road accumulated solar energy during the night time, which was converted into electric energy and guided the cyclists by illuminating the roads at night. This road creates a beautiful illusion of starry nights by the LED lights that illuminate the road.

SolaRoads, in association with the local council, is working to create technology to provide illumination in other states and localities of the Netherlands. In California, USA, it is planned to construct these solar roads there in the future (Katharine, 2014).

<u>Solar Roads in France</u>

The French government is planning to install solar panels in roads. Within five years they will cover 1000 km of road. This whole project is capable of covering 5 million of the total population, which is nearly 8 percent. The solar panels that are being used are waterway panels; this technology is known as photovoltaic and is introduced by the civil engineering firm, Colas, in October last year (2015). The French Minister of Ecology and Energy decided to increase the tax on fossil fuels and that capital is being used for this project (Wang, 2016).

Figure 5-10: Installation of solar panels in France (Wang, 2016)

Figure 5-11: Solar roads in France (Wang, 2016)

It is true that France is installing solar panels over 1000 kilometres of road, but they are not the one who initiated that; the Netherlands in 2014 used solar panels for bicycle pavements. The Agency of Energy and Environment Management in France did the calculation that just 4 metres of the solar road is sufficient for the energy needed for one household, while 1 kilometre will be able to provide power for 5000 of the population (Wang, 2016).

Waterway panels that cover the entire solar road are pasted directly on the asphalt, a technology developed by the Colas Company. Waterway panels are tested for 20 years of normal traffic. The panels did not move when bearing the heavy weight of trucks, Herve'Le Bouc, CEO of Colas, was reported as saying. Panels are made of this film of polycrystalline silicon which produces energy. The panel has also survived a snowplow test, but still the Agency is recommending care for conventional roadways.

Tax from fossil fuel is estimated as up to 300 million euros, which is equal to 440 dollars (Wang, 2016). All this money is used in funding this project, and the project is moving forward as the green source of energy, regardless of the many concerns remaining, like cost effectiveness and safety. Although the location for this project is not decided yet, Tenders have been issued.

Other wind and solar energy innovations

Europe's electric vehicles

Electric vehicles face a major barrier in the development of advanced and effective batteries that can store energy. There is a need to have improved the system of fuel cells as well as hydrogen systems, in terms of a better system of production as well as better distribution, in order to gain a competitive advantage over the traditional fuel-based automobiles that are used. The weight of the vehicle is another important vehicle that needs to be considered, as it impacts the consumption of fuels as well as the safety of vehicles (Stantchev & Whiteing, 2010).

San Francisco's electric car charging stations and Adelaide

Figure 5-12: Charging station (San Francisco, 2009)

These car charging stations are known as EV stations; they have electric points for charging cars, recharging points as well as EVSE. These stations are the powerhouse for energy supply used for recharging electronic vehicles or the hybrid vehicles that run both by electricity as well as fuel.

Geothermal stations of Stockholm, Paris

In Stockholm, Paris, there is a usage of geothermal equipment that can harness the heat energy of commuters. Jernhusen, a Swedish realtor, is spending 1 billion SEK in order to innovate the Central Station of Stockholm and placing an innovative system of geothermal that can capture the body heat of the daily commuters of the station. The ventilation system of the station is equipped with heat exchangers that can convert the extra amount of the heat from the body of commuters into hot water; this hot water will be then pumped in order to heat the offices in the Kungsbrohuset building nearby.

By installing this system, the cost of energy requirements of the Kungsrohuset building can be saved by up to 25%. This is a big saving, considering the cold winters of Sweden and the high costs of the gas required to heat up the buildings. This project can be adapted on a commercial basis in many countries as well leading to a significant reduction in the usage of non-renewable fuels, as well as a reduction in the harmful emissions of gases.

An initiative similar to the geothermal station of Stockholm is practised at the Rambteau station of Paris metro. In this metro station, the heat that is generated by the passers-by of the platform as well as the corridors and the heat energy that is generated as a result of the movements of the train is used to generate heat for the floor of housing projects. The block of the apartment that is heated by the heat energy generated from the metro station is connected by the stairwell to the station that houses the pipelines. This system also reduces the costs of excavations, making the project cost effective too (Jones, 2011). This project reduces the bill for heating by one-third.

Driving factors for the SolaRoads

The driving factor for the technology of solar roads is the need to build a road that conserves energy and is self- sufficient, and also, the construction of roads that just cannot sustain their own energy requirements but provide energy to the nearby households.

Barriers that the solar roads face

- These roads are very costly, as one solar panel costs as much as $7000 and there is the requirement of billions of such panels for the construction of the entire road
- There is a need to spend lots of time as well as money for the installation of these roads
- The construction of these roads requires the training of the members of the crew
- The time taken by the electricity generated by these roads to cover their cost of construction is quite high (George, 2015)

Economic benefits of Solar Roads

The solar roads have heavy manufacturing requirements leading to the creation of many new jobs. It takes 10 hours to assemble five billion solar panels; this means there is a requirement of 50 billion assembly hours. This amounts to a total of 2000 working hours in a year (Solar Roadways, 2016).

The economic benefits of using solar roads can be judged by the fact that just a mile of a solar road can produce energy enough to provide power to about 500 houses. If we assume that one panel produces 7.6kw hours power every day, although one 12' by 12' panel costs around $6,900, this cost can very soon be covered by giving energy to the locals and charging them in return.

Environmental and sustainable benefits of solar roads, the wind and geothermal energy road innovation

The energy generation from solar roads as well as other such innovative initiatives is entirely dependent on renewable energy sources leading to the significant reduction in pollution to a significant level.

Such initiatives lead to a decrease in the dependence of conventional energy sources such as fuel and coal.

These are comparatively cheaper energy sources, as they can cover their own costs of construction over time and lead to additional income. The only cost elements attached to these methods are in their set-up stage.

The construction of solar roads in Australia can serve as a reason for causing an economic recovery in the nation. This is because it will take more than five billion Solar Road Panels of the dimension 12' by 12' to cover all the important road systems of Australia. The project can have immense manufacturing requirements and so will lead to the creation of many new jobs. This will enable the retention of the workforce from jobs that are obsolete, such as coal miners and the workers who are engaged in working in the asphalt road construction factories, and will lead to the creation of jobs that are Green Collared. These initiatives will enhance the economic conditions of Australia. Solar roads can also cut through the ice and enable saving of lives; also increasing the life of these roads will cause a reduction in the pollution of the water table by salts.

The other benefits of using solar roads are tremendous, as they are a giant step to a self-sufficient and prosperous world. These solar roads would enable the creation of an economy that would not have any shortage of power and the dependency on foreign oil would also be comparatively very less; the solar road systems would cause a significant reduction in the levels of pollution, thus being highly environment and eco-friendly. This is because these roads would not emit any greenhouse gases (Green Energy, 2015).

The main benefit of using solar panels is that it will lead to the reduction of the emissions of the greenhouse gases by half the amount. This is a highly viable project and can be adopted all over the world. The solar roads are a self-sufficient project and will be able to fund their costing by themselves in the coming years. These road projects can be customised in accordance with the geographic location in which they are planned to be set up. A country that is more prone to snowfall and ice can have a solar roadway with a heating system to automatically prevent the snow layering on the roads. With the use of LEDs in the roads, there can be lighting achieved in the roads themselves (Green Energy, 2015).

Solar Roads in the United State of America

Driving on solar panels is not dream anymore, though it will take time to reach to a level of adoption. Once we fully implement solar roads, we can easily elucidate our energy requirements. Solar power roads have many more benefits that have not yet been predicted. Not only they are capable of producing electricity, they also can provide different services like melting snow if they are built by a heating element; in the same fashion they can be made up of solar and glass, and therefore, can light road signs and can guide drivers. The energy crisis in the USA can be overcome by replacing interstate roads with solar roads. Assuming one panel of road produces 7.6kw hour of power each day, it means one mile of solar road is capable of providing energy to 500 houses. It is obvious that costs on the solar panels are high, a 12x12 panel only costs about $6800, but when customers pay for their power supply, costs can be counterbalanced, and moreover this is a pollution-free source of energy.

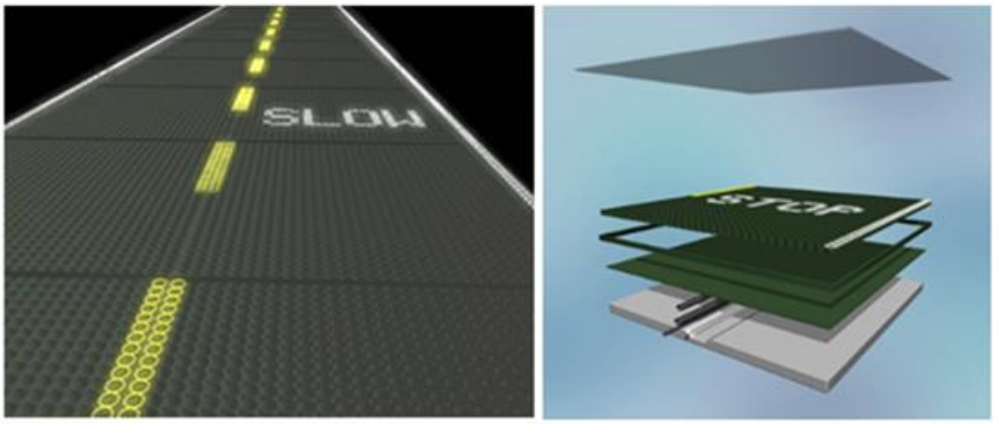


Figure 5-13: Prototype in U.S (Christen da Costa, 2010)

The Department of Transportation grants $100,000 to build a prototype first. Once verified that these kinds of road are viable and need much less maintenance, the result will bring this concept into reality and the possibility of converting interstate roads by this technology (Christen da Costa, 2010; Christen da Costa, 2011)

Solar roadways to prototype first ever solar road panel

Scott Brusaw designed the panels for solar roadways; these roadways contain more technical elements; they have a built-in heating element within, so when it snows they can melt ice; they also have LED implanted within the cell, and these lights can provide drive different information and make travel lines. These panels are made up of the solar cell and the top cover is tough glass that replaces the asphalt coat that is usually used on conventional roads and parking lots.

Possibly panels could produce "*Intelligent highways that will double as a secure, intelligent, decentralized, self-healing power grid which will enable a gradual weaning from fossil fuels."* (Inhabitat, 2009)

Solar cat-eyes and solar road studs

Luna Road lights are new, advanced cat eyes; this extraordinary technology offers customisable structures, and choice of echo friendly road safety.

Solar road structure is safer as it can melt ice, and moreover, salt pollution will also be reduced. This new system is capable of gathering energy during summer, and storing it in thermal banks. This stored energy is used for cutting ice in the winter season. ICAX exhibits Solar Road Systems on the Toddington motorway; the assignment is supported by the Highway Authority.

Figure 5-14: Solar cat-eyes (Lighting Matters, 2015)

This new structure consists of two solar collector groups; these collectors are embedded in the road surface and a thermal bank. The collectors are shown in orange and thermal storage in blue below.

In the first, it is shown that thermal storage can be positioned beneath the road, and the second shows that it can be located adjacent to the highway (ICAX, 2011, 2015).

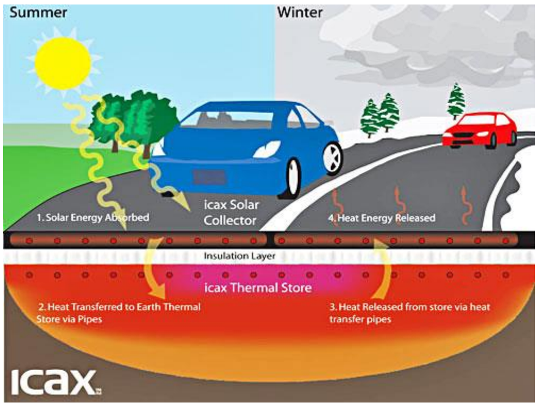


Figure 5.15: Thermal location (ICAX, 2011, 2015)

On the Toddington highway, energy collection is observed and in winter, the melting of snow is also demonstrated. The cold storage cooling capability is verified in summer.

This whole project took around two years. It was monitored by a transport research laboratory autonomously. TRL acknowledged that heat transfers from thermal reserves during the winter season and it worked exactly as predicted in the design of this project.

Interseasonal heat transfer will be used in cutting ice from roads and airport runways and public places.

- It keeps people safe by preventing accidents

- Due to cooling capacity in summer it maintains temperature, which increases the life of the road
- Prevents freezing in winter
- It is eco-friendly as salt pollution is reduced

Successful Demonstration - at Hiroshima by Misawa

In Japan, the Misawa solar road system is working practically; they are cutting ice from the road using this technology. Misawa contacted ICAX as they want to demonstrate their technology in Japan, a licence arrangement was settled and Misawa demonstrated in Hiroshima (Figure 5-16)

Figure 5-16: Clear snow using under road heating (ICAX, 2015)

SURFACE FEATURES	SOLAR ROADWAYS	CONCRETE	ASPHALT
Flat place to walk and drive	●	●	●
Provides parking	●	●	●
Provides traction	●	●	●
Doesn't soften at high temperatures	●	●	
Generates energy	●		
Intelligent	●		
LED lights for lines and signage	●		
Remains snow/ice free	●		
Impervious to potholes	●		
Can protect animals	●		
Modular for faster maintenance	●		
Requires no paint	●		
Aesthetic benefits	●		
Has ROI	●		
Facilitates energy independence	●		
Can charge EVs with clean energy	●		
Water can be stored, treated or moved	●		
Provides a "home" for cables, wires	●		
Can provide emergency warning system	●		
Expandable Technology Package	●		

Figure 5-17: Features of solar road (Solar Roadways, 2016)

5.5 CASE STUDY 4: FUTURISTIC HIGHWAYS

The Netherlands road construction has come through another revolutionary discovery. It is developing a highway which is Tron-like and glows in the dark. This will be the first highway in the world that will glow in the dark. The testing of this project has already begun. A section of 500 metres of the N329 Oss highway has been equipped with this technology. These roads will not only glow in the dark but also will give weather indications.

The name of this project is the Smart Highway Project and it is a project that is led by Daan Roosegaarde of Studio Roosegaarde and Heijmans, who is a civil engineer in the Netherlands. The idea behind this project is the creation of highways that are interactive and sustainable in nature. These highways will be covered by paint that glows without light, by absorbing energy in the day time. These paints can glow for a maximum of eight hours. This project has been awarded the Best Future Concept at the Dutch Design Awards.

This can be a very smart and efficient initiative to conserve and save energy, as, if this project becomes successful, they can replace the street lights. These futuristic highways will lead to the creation of safe and sustainable thoroughfares. Heijman claims that this technology can be a replacement of the lighting posts that are placed on the sides of the roads of the highways. Also, this technology can serve as a better alternative to roads in the areas where lighting and electricity are not present (Dube, 2014).

Figure 5-18: Glowing lines and Dynamic paint

This can be a very smart and efficient initiative to conserve and save energy, as, if this project becomes successful, they can replace the street lights. These futuristic highways will lead to the creation of safe and sustainable thoroughfares. Heijman claims that this technology can be a replacement of the lighting posts that are placed on the sides of the roads of the highways. Also, this technology can serve as a better alternative to roads in the areas where lighting and electricity are not present (Dube, 2014).

Before this project gains acceptance from the Netherlands Highway Agency, there are some unanswered issues that need to be addressed regarding this project. First of all, it is an important aspect to understand what is the visibility range of these paints? Also, these paints should make the markings of the road visible at distances that are safe for drivers. Also, there is a need to understand the effect of the paint on weather conditions like rainfall, winter with low sunlight, rains etc.

UK landscaping company Pro-Teq launched a similar project in which the roadways and sidewalks were illuminated with the aid of sprays as a replacement for street lights, This technology is being applied in the Christ Pieces which a park around the Cambridge City Council.

There are certain issues in the implementation of this technology, such the high costs of the glow-in-the-dark paints and also the uncertain product durability of these systems which can lead to problems such as high maintenance costs in the future. Also, there is a need to test the toxicity and the environmental effect of these paints (Dube, 2014).

Success in this area will lead to the making of intelligent roads and the implementation of innovation techniques for making better roads and giving value to customers. Roosegaarde is all set to introduce this design in the west coast of the USA with the aid of the technology of Google that has transformed innovation in the transportation sector (Prakash, 2012).

Driving factors to the smart highways in Netherland

This project is a very smart initiative in conserving energy as these roads can replace street lights. These highways would be futuristic and safe. Also, these roads will serve as an alternative to areas where there is no presence of electricity.

Barriers to the project

As this is still a test project there is a need to address certain issues pertaining to these roads, such as the high costs of the paints and also the durability of these products and their environmental implications.

Economic Benefits of these roads

The economic benefits of these roads are associated with the amount of energy that can be saved by permanently shutting off the streetlights by the use of the glow-in-the-dark roads. In the year 2011, when the street lights of England were shut off for a night to reduce the carbon emission, there was a net saving of $668,000. So the use of these roadways could make a reduction of $1,337,000 annual spending if only one-third of the UK's street lights were shut off for a certain time or they were dimmed.

Environmental and sustainable benefits of the Netherland glow in dark roads

The main idea behind this project is not merely the construction of sustainable ways of lighting the roads but also making the roads more efficient and less accident prone. This project aims to bring about revolution and re-design in the highway systems and the roadways. It will lead to the development of an internal system of navigation by connecting automobiles.

5.6 CASE STUDY 5: RECENT INNOVATIVE TECHNIQUES USED BY RTA NSW

SCATS (Sydney Coordinated Adaptive Traffic System) or the RTA, was developed to bring traffic control to Sydney originally. Now, RTA has become internationally accepted and is being used in over 141 cities of over 24 countries in the world. RTA is controlling 32,000 intersections all over the world. RTA has established itself as one of the most popular and globally accepted systems of traffic control. NICTA is the Centre for Research in Information and Communication Technology of Australia, which was established in the year 2004. It is actively involved in finding innovative methods of road traffic control by the aid of research and development and has over 400 researchers (Kilby & Johnson, 2010).

The road network of NSW is an important asset of the state that provides access to travel and transportation of freight across places. The entire roadways are divided into four sections that are:

- 17919 km that are managed by the State Roads
- 2946 km that the regional and the local roads manages
- 18486 km of roads that are managed by the council with the aid of funds for grants from RTA
- 143783 km of local roads that are managed by council

The first two categories that include a stretch of 20865 km of roads have a flexible component in the pavement.

<u>History of RTA</u>

The beginning formative five years of the RTA and NICTA have delivered a highly innovative solution that has been very successful in the management of traffic by RTA (Geers, Tyler, Hengst, Huang, & Quail, 2009). This collaboration has led to the successful completion of many systems and trials and prototypes for bringing about improvement in the inflow of traffic in the major highways of the south Sydney region. This system works by a method that enables the estimation of the queue length on the basis of information via upstream loop detectors. This system enabled the detection of traffic delays especially at the time of greatest traffic congestions. This method was being presented later on at the ITS World Conference (Geers, Tyler, Chong-White, & Johnson, 2010).

Aims of the projects of RTA

The RTA is actively involved in many types of research in key areas, such as the handling of the conditions that are oversaturated. At this condition, the traffic increases to a level that requires the vehicles to stop at many places before a congested link is cleared. Such high traffic congestion is a major source of heavy wastage of fuels that are unavoidable in nature and cause major emissions. Apart from this, such slow moving traffic often frustrates the driver and delays them. NICTA is involved in finding solutions for avoiding such situations.

The RTA is also working on extending the use of the technology for the estimation of the length of the queue. For this, the method that has been employed, the advent of queues for longer time durations is considered as an indicator of the areas that have high congestion of traffic. It is been investigated to ascertain the use of the technology for the automatic detection of queues in real time, when they are forming. This system can raise an alarm at the time of the queue rising to a limit when the nominal capacity of the roadway approaches. This would lead to the continuous flow of traffic. This alarm can enable the traffic authorities to take steps to ensure that the green time wastage is avoided.

The RTA has also introduced the SCATS system, which is a system of traffic control that is highly adaptive. This technology is capable of automatically adapting of the length of green time, according to the conditions of traffic. The RTA in collaboration with NICTA is also working on developing a method that automatically computes the fixed time on the basis of the recent history of traffic. This plan has certain features, such as operator intervention and operation for fall-back. This system investigates the automatic portioning of days in the time frame of the same traffic demands and also the determination of conditions of traffic that are appropriate and can form the basis of both base and robust plans.

SCATS are coordinating the signals of traffic via the many facilities that exist. This leads to the determination of when the signals of traffic can be grouped to bring coordination and establishment to the dissolution of these groups. There is research ongoing for finding ways of applying models of higher levels regarding the coordination and comparison in the traffic control system.

Phases of the road innovation program of RTA

The first phase of the innovative project of RTA focuses on bringing about coordination in traffic signals. The RTA has established a method via which there can be groups formed for coordination of the traffic signals. Coordination is very important in lieu of the world outlook for the reduction of greenhouse gases. Coordination means the establishment of a system that would lead to the same cycle times of the adjacent intersections, which would be calculated to ensure that a minimum of one upstream movement in the traffic could pass a downstream intersection without having to stop, or reducing the chances of stopping.

This is an environment-friendly technology as the stoppage of the vehicles ceases resulting in a continuous flow of traffic. This would lead to significant reduction in the emission of greenhouse gases. During acceleration from a stop, there is an emission of high levels of carbon dioxide and other pollutants like hydrocarbons and nitric oxide. According to the report of Colyar in 2001, the emissions of the vehicles are greatest at the time when they are accelerating and this reaches the lowest level at the time that the vehicles are idling.

Coordination can be achieved by the matching of the cycle times at intersections that are adjacent. Each individual intersection has a cycle time that is desired and depends on upon intersection phasing and the demand level of the intersection, which indicates the number of vehicles that wish to use a particular phase. Coordination can be applied to the intersections that have the same desired cycle lengths. After the establishment of a correct and appropriate offset, all the benefits of reduction in the stop and reduction in the delay of movements that are coordinated can be achieved. This would lead to very little change in the delay that is experienced by the movements of the traffic.

The recent innovative projects of the RTA also focus on the forced coordination of the intersection having cycle times that are different. This coordination is comparatively costly. This leads to using the longest cycle time to accommodate demand, and then to higher delay levels of some lower demand intersections. This delay can be balanced by decreasing the stops and the delay for traffic that is coordinated. Forced coordination is applicable in the cases when the balance favours the traffic that is coordinated (Geers et al., 2009).

The reduction of the delay is one of the main objectives of coordination. The innovative projects of the RTA brought coordination of the intersection by reducing the delay. When a vehicle is stopped by the accumulation of a delay, a very little amounts of carbon dioxide load are caused. When the vehicle is stopped by force, then it is accelerated back to a speed of cruising and the carbon dioxide that is produced is much greater (Chong-White et al., 2008). The carbon dioxide emissions are important to bring about balance to create coordination. If the stops are reduced to a significant level there can be a high level of delay expected.

Live Traffic NSW

The new Live Traffic NSW website of the RTA was launched in the year 2010. This website gives motorists live real-time news of traffic incidents that can have an effect on their journeys. This website enables motorists to travel in the best possible way and make better decisions related to travel.

The website gives:

- The real-time information regarding traffic and the incidents of fire, flood and other events
- Access to 66 live cameras that have updated images in the duration of each minute
- The information regarding the flow of traffic on major NSW roads that show whether the traffic lights are heavy, slow or medium
- A trip planner that allows the user to see the journey on a map and also filter information to view real-time conditions and road schedules
- The features of the trip planner that involve checking of the stations of the heavy vehicles, rest areas, train stations nearby, ferry etc.

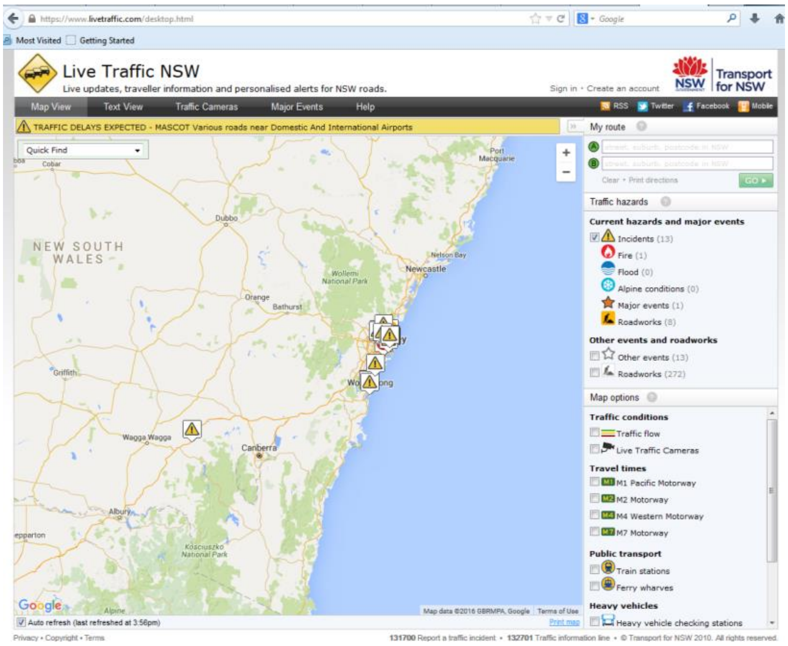


Figure 5-19: New Live Traffic, NSW web page

Use of ICT by RTA

RTA is working for the application and development of Information and Communication Technology (ICT) for a better road management system. Along with the association of NICTA, RTA has developed the leading logistic tool in the world, ICT which can make the fleet's high efficiency even better. . By the aid of two-way video and broadband systems, there is high demand and development of networking at a larger scale. The 'work from home' option is made more prevalent by the development of ICT and people are choosing to work from a title hub for few days in the week, while road traffic congestion then becomes significantly reduced. Road traffic management is now done by using the innovative Data Driven Planning and Operations; in this method real time collection of transport data takes place. The data is gathered every second and also for a long time scale. Inductive loops and toll gates are used for the collection of data by the analysis of videos from cameras' quantitative traffic measurement. Passive indications about people, vehicles and mass can be done by triangulation and cell tower association via mobiles. Satellite navigation systems and smart phones can be used to give accurate information regarding the record of people and movement of vehicles via some applications and log movement. This would also enable the gathering of information about destinations and modes of travel as well as travel pairs. The buses and trains of Sydney are now equipped with GPS systems and their real-time location at any point of time can be known. So the ICT use has made it possible to assess a large amount of traffic information that can enable a better understanding of making the traffic system better and also predict traffic behaviour, the correlation of data from many sources, and better operations and adaptations of traffic control signals in accordance with actual demand. Also, the use of ICT will allow better insights for improvements of the traffic management systems and traffic safety and incidents.

Making the transport infrastructure more efficient

According to the draft of the innovation plan of the RTA, there is stress on using technology to make the existing infrastructure of the transport system more efficient. There is a plan to make the speed limits optimised in an adaptive way, having efficient control of the traffic signals. NICTA and NSW are planning together, managing traffic demand by the aid of dynamic pricing, and the use of GPS for the control of freight paths. The plan includes information regarding real-time traffic, voluntary changes in the timings of the trips for avoiding traffic congestion and controlling peak traffic demands. Use of cooperative ITS would allow people, vehicles and the infrastructure to be able to signal locations and hazards by the aid of DSRC technology and movement.

NICTA and the RTA have together developed an advanced traffic light algorithm. This algorithm enables the control of the traffic lights at roundabouts that are complex in the region of Albion Park. This system uses simulations and has shown over 8% traffic performance improvement. The enhanced efficiency brought by this system can lead to billions of dollars of cost saving via better management of congestion.

Optimisation of costs

The models of the ICT use simulations and visualisations that can result in the exploration of the future of the transport system. RTA in association with RMA and NICTA is working on the improvement of the structural health of bridges and is working on the Sydney Harbour Bridge, which uses the machine to fuse the data sensor in a manner in which any type of structural abnormalities is highlighted (Ling, 2003).

The Continuous Flight Augur (CFA) pilling that is used at the Tarcutta bypass

- This type of pilling has contributed to many additional benefits such as;
- The pilling method is less costly than in comparison to the traditional pilling methods in use
- This method is approximately twice faster than the traditional method of pilling
- This method is free from vibration and the noise creation is quite lower in the method, which makes it convenient and better for the nearby residents

The moveable barrier system of the Inner West Busway

This was the pilot project and first introduced in Australia. This system uses a transfer machine to transfer the barrier and the concrete from one side of the lane to another. This method has benefitted the road construction sector in Australia by improving the condition bus travel and its reliability over the Victorian roads carrying over 200,000 passengers per week.

The moveable barrier system of the Inner West Busway is a pilot project introduced in Australia. In this system, there is the use of a moveable barrier system that transfers concrete from one side to another. This method of construction has made the roadways of Australia more reliable. These barrier systems offer roadway configuration for real time and maintain positive protection in between the lanes (Lindsay Corporation, 2015). The moveable barrier system that is designed by Quick Change is highly flexible and offers a positive barrier for traffic. In this system, there is a need for a wall of interlocked barrier that can be lifted and adjusted by the aid of a transfer machine. These movable barriers have the facility to allow the contractor to increase the size of the work zone in the time of low traffic. This system enables an accelerated construction process.

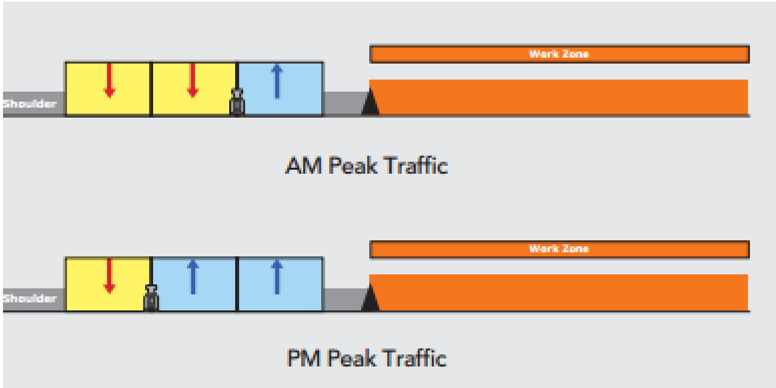


Figure 5-20: The traffic switch Cross Sections

The system leads to the reduction of the congestion of traffic by making the opening of more lanes feasible during the peak hour of traffic (System, 2015). This system creates a flexible and a positive barrier of traffic in between the lanes that are opposing or in between the zones of construction and the motorists. The system is made of a wall of a barrier of 1 metre that can be lifted and replaced by the help of a transfer machine in order to result in the creation of an additional space for work zone leading to the provision of more lanes in the time of peak traffic, so that traffic congestion can be reduced.

QMB, also known as the Quick Change Movable Barrier System, enables the contractor to increase the working zone sizes in the time of less traffic congestion in order to create haul lanes using bigger equipment that would enable the acceleration of the process of construction.

Figure 5-21: Use of moveable barrier system (Lindsay Corporation, 2015)

The barrier can be moved many times a day so as to reconfigure the roadways in order to increase the number of lanes at peak traffic times.

Driving factors of using moveable barrier system

- The moveable barrier system can be used for controlling the traffic congestion
- It is used to enable positive protection by barriers between the lanes
- The driving factor for the construction of the moveable barrier is to manage traffic inflows in areas where there is high inflow of traffic and the redistribution of the unused traffic capacity from the directions that have off-peak times, in order to give more lanes to the peak traffic locations.

Barriers to the project

The project is costly, making its implementation difficult for low budgeted construction programs, which are one of the prime barriers of the project.

Economic benefits of the project

The average cost of purchasing a transport and a transfer machine is around $ 650,000. The cost of the barrier is around $500 for every metered block. The total cost of the barrier for one mile comes to $800,000. There have been surveys conducted in which the respondents have stated the benefit to cost ratios; it was 2.2:1 in Australia (Bain, 2001).

<u>Treatment of the mines that are underground in the Hunter Expressway</u>

This innovative method adopted by the RTA has brought many benefits such as lowering the adverse impact in the maintenance of the roads in the Hunter region, owing to adverse cultural and environmental conditions; also the treatment of the mines has come up with a cost-effective solution to tackle the adverse cultural and environmental conditions.

Diamond grinding applied at many road maintenance projects

By using diamonds drills for grinding, easy removal and smoothening of the irregularities of the road surface is achieved. These are caused as a result of construction and traffic leading to the development of grooves in the roads. Diamond grinding paves the road surface and leads to the formation of a uniform road surface, resulting in a road that is smooth, safe and quiet.

The treatment of soft soils by the use of vacuum consolidation technique in the Ballina bypass

This technology has been recently introduced in the Australian road construction sector. This technology is cost and time saving in comparison to the already existing techniques.

This technology aids in the consolidation of soil and in the formation of a stable soil foundation that improves construction. This technology is used in the construction of roads in the Pacific Highway (Chong-White & al, 2008).

5.7 CASE STUDY 6: PRECAST PRE-STRESSED CONCRETE PAVEMENT

Background

In the last 10 years, the State Transportation of the United States has been very keen in adopting innovative methods and using techniques of road construction at a rapid speed without disturbing the normal flow of traffic.

Precast Pre-Stressed Concrete Pavement (PPCP) has come up with an efficient solution to attain rapid construction of the roads that is durable and does not disrupt the normal flow of traffic for long. In the feasibility study conducted by the Centre for Transportation Research (CTR) at the Texas University, Austin, Precast Prestressed pavement was used following the implementation of the technology by the Federal Highway Administration, which was conducted by the CTR. After the study, there was a construction of 0.7 Km of the PPCP pilot project. This pilot project was conducted near Georgetown, Texas.

The technology of using precast concrete pavement involves the use of innovative methods for road construction in order to be able to repair and construct roads at a rapid speed. The components that are used in the precast pavements are assembled and fabricated somewhere else and then transported to the site of the project. They are then installed on an existing pavement. This system is highly effective as it requires less time for field curing, which gives strength to the road before the road is put to use for the traffic. This technology can be used effectively for the purpose of quick road repair and reconstruction. The technology can lead to the reconstruction of roads that have high traffic influx. Presently, the technology is used for continuous rehabilitation and intermittent repairs (D. K. Merritt & Tayabji, 2009; U.S. Department of Transportation: Federal Highway Administration, 2015).

Intermittent repair is done of PCC or Portland Cement Concrete pavements. The precast concrete pavements result in the need to repair the joints and cracks or full panels. This technology is used for slab panel seating and joints transfer.

The continuous application uses full-scale rehabilitation and reconstruction of PCC and asphalt pavements by the use of precast concrete panels. The continuous application is done by the use of precast pressurised concrete pavement. In the United States in the decade of the 1980s, this technology was used and many cast-in-place prestressed concrete pavement projects were constructed (D. Merritt, Frank McCullough, & Burns, 2003).

The use of the Precast Prestressed pavement technology is the initiative of the Federal Highway Administration via the Concrete Pavement Technology Program and the Texas Department of Transportation (D. K. Merritt & Tyson, 2006).

<u>The Precast Prestressed Concrete Pavement System</u>

This system comprises a series of panels that are precast and placed in the longitudinal direction for post-tensioning after they are installed on the site. These panels can also be positioned in the direction of the panel’s long axis (D. K. Merritt & Tayabji, 2009). The PPCP system has the following basic features:

- The size of the panel is a maximum of 38 ft. and is 10ft long. The thickness is around 7-8 inches.

- There are two types of panels that can be found;

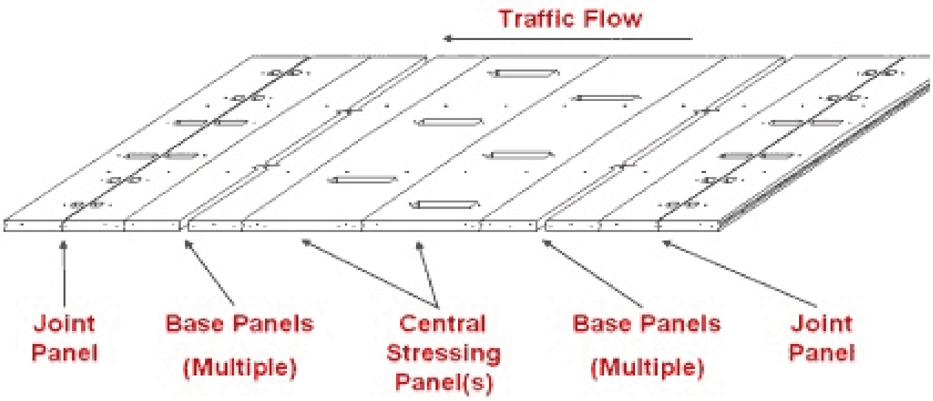


Figure 5.22: The schematic cross-section of dowel assembly (D. K. Merritt & Tayabji, 2009)

- Base, joint and central stressing panels
- Base and joint stressing panels
- These panels have epoxied joints that are tongue-and-groove type
- The post-tensioning details of the PPCP system are:
    - It has mono strand tendons of 15mm diameter which are 7-wire; they are spaced at 24 in.
    - The tendon load PPCP is 75%
    - The prestress force of the tendon can sufficiently withstand around 150 to 200 lbf/in2 at the mid-point of the panels (D. K. Merritt & Tayabji, 2009)

Figure 5-23: The PPCP over polythene sheet (D. K. Merritt & Tayabji, 2009)

Considerations of the pavement

- The system of the PPCP needs a panel for placement over a smooth base, which makes the friction in between the panels as little as possible. This also minimises the pre-stressing force invested in lowering the friction between the surfaces (S. Tayabji, Ye, & Buch, 2013; S. D. Tayabji, Barenberg, Gramling, & Teng, 2001).
- The base of the PPCP and its foundation are made of superior quality, which enables reduction of the deflection of the slab and at the joint expansion (D. K. Merritt & Tayabji, 2009).
- The PPCP can be made in a way so the residual pre-stress is the minimum attained to about 150-200 lbf/in^2. The residual pre-stress thus generated increases the flexural strength of the concrete (D. K. Merritt & Tayabji, 2009).
- These systems can be put to use for the expansion joints at about 250-400 ft. The longer the spacing of the joint, the more is the requirement of the pre-stressing tendons that exert greater pre-stressing force and enable the balancing of the higher losses of the pre-stress (D. K. Merritt & Tayabji, 2009)
- The size of the pre-stressing tendons is selected so that the desired stress levels are met at the end of the slabs. According to the standards of the United States, the size of the tendon is maintained at 0.6in.(S. D. Tayabji et al., 2001)

- In order to determine the fatigue cracking, the AASHTO mechanistic - empirical design procedure is used (AASHTO, 2004)

Considerations for installation and the fabrication of the panel

These panels are produced in mass, so there is a requirement of space for storage of these panels at either the project staging area or the plant fabrication. These panels require transportation from the storage area to the site of the project, so there is less intermediate handling of the panels, minimising damages of all types. Owing to the heavy weight of these panels, there is a requirement of a heavy mobile crane for the transportation of these panels (AASHTO, 2004).

Below, the installation procedure of the panel discussed;

- Preparation of a base or an interlayer in the case of an overlay application
- Placement of the polyethylene sheet above the base layer
- Installation of the joints of the panels as well as the successive base and central pre-stressing panels according to the requirement
- Application of the partial post-tensioning to each of the panels that are placed, which would ensure a proper fit of the panels at its transverse joints and also the proper alignment of the panels
- After all the panels that need to be post-tensioned are kept in place, there is a requirement of threading the tendons via the tendon ducts and the application of pre-stressing force at each of the tendons.

The PPCP projects that were undertaken in the United States were;

The Pilot project undertaken at Texas- this was the first project of its kind and it was undertaken in Georgetown in Texas in the year 2001. In this project, around 2,300 ft of two-lane pavement was placed on the road. The pilot project had many challenges for the implementation of the PPCP technology. The meshing of the precast concrete and the specifications of the concrete pavement were a challenge for the implementation of the project. There was the requirement of flexibility by both the precast supplier and the Texas DOT. Now the project is well performing and the maintenance costs and other issues related to maintenance and repair of the road are not reported (S. Tayabji & Hall, 2008).

The demonstration project at California -

This project was undertaken at the Caltrans by the aid of the PPCP system using widening of the heavy traffic lanes of vehicles and also for the reduction of the congestion of traffic. This project resulted in the addition of 27ft lane and 10ft to the lanes that existed in the eastbound direction.

The Missouri Demonstration Project

This project employed the testing of the feasibility of the use of the PCCP alternatively for the pavement construction and rehabilitation at a rapid rate (Federal Highway Administration, 2009).

The demonstration project of Iowa

This project was started in the year 2006. It included the installation of the precast bridge slabs on SR60 in the Sheldon area. This bridge was a new construction that required no traffic disturbances at the installation time. This project involved tying the approach slabs to the abutments of the bridge, making the approach slabs able to house a bridge skew of 30-degree (Federal Highway Administration, 2009).

The demonstration project of Delaware

This project was initiated in the year 2009 when the Delaware DOT planned to initiate the use of the PPCP system in order to bring about the pavement rehabilitation along the northbound Route 896. This design has the PPCP panels of 8in (Federal Highway Administration, 2009).

Economic benefits of using the PPCP

One of the greatest benefits of using these pavements is that it reduces the time of construction and improves the road durability, which in turn leads to a reduction in the costs that are incurred for the construction and the rehabilitation of the pavements. The poor quality of the pavements results in the high amount of user costs as it causes wear and tear to the automobiles that run on these pavements. According to a study in America, around $41 billion is spent per year on repairing the vehicles owing to the bad conditions of the roads. The PPCP being more durable and smooth significantly lowers the costs of vehicle repair.

The system provides quick rehabilitation and reconstruction that is durable. Also, the higher costs of the system are a negligible offset considering the quick installation that reduces the closure of the lanes for a longer time period.

Environmental and sustainable benefits of using the PPCP system

Another benefit that is associated with these prestressed pavements is that there is a futuristic prospect of increasing the season of construction of paving the roads. The casting and the curing of the precast, prestressed pavements are done in an environment that is controlled, leading to the continuation of the construction of the pavements even in the adverse weather conditions, whereas the normal pavement construction gets severely impacted in adverse weather conditions. So these pavements are unaffected and can be constructed even in situations of subfreezing or hot humid temperatures (U.S. Department of Transportation: Federal Highway Administration, 2015).

Benefits of the PPCP Systems

The improvement in the durability of the pavement is one of the major benefits of this system. These panels are cast in an environment that is controlled, enabling the manufacturers to make a mixture of concrete that is highly consistent and having a superior uniform quality. Owing to the reason of these mixtures being transported to a relatively shorter distance from the plant of manufacturing to the destination of use, there is the use of low permeable mixes that are durable in nature and that have a low water-to-cement materials ratio lowering the chances of occurrence of problems like segregation and flash set. Also, this method is superior to the traditional cast-in-place concrete pavement as it does not have an issue such as “built-in curl” owing to the difference in the gradient of temperature and moisture content. Also, this method is devoid of issues such as improper air entrainment.

By prestressing the pre-cast pavements are made more durable as they get a compressive stress that greatly minimises the occurrence of cracking in the pavements. This can be validated by the fact that the cast in place pavement of 6in. on I -35 Texas in the year 1985. This construction site had almost no requirement of maintenance over a span of 19 years.

Apart from increasing the durability of the pavement systems, by pre-stressing, also the slab thickness can be reduced to a significant level. A pre-compressive stress helps in minimising the tensile strength of the load of the wheel of the automobile in comparison to the pavements that are not pre-stressed.

5.8 CASE STUDY 7: TONER RECYCLING FOR ROADS

Figure 5-24: Recycled toner for road pavement

Australia has introduced a new innovative technology in road building material. The roads are being built by the use of old computer toner cartridges. Using the computer toners as an adhesive material is a very effective concept, as using green asphalt leads to a reduction in the emissions that are emitted for the production of roads by over 40%. This would soon enable the Australian roads to be built by an environment-friendly technique.

These roads are environment-friendly in nature and are made of asphalt mix that contains recycled printer toner. These mixes are being used on the roads of Sydney.

This is the first use of the waste from toner in the world and it originated in Melbourne in the year 2013 and was followed in Sydney in 2015. This technology is known as Toner Pave. The developer of this technology was a contractor of the city roads, Downer, in association with the recycling company of printer cartridges, Close the Loop.

In this technology, the toner is made by blending it with oil and is about of 40% greater efficient in energy than the standard bitumen that is used for the construction of roads. This technology leads to the saving of carbon dioxide by about 270 Kg per tonne compared to the carbon dioxide emission of traditional roads.

This technology needs to be circulated and popularised as the entire wastage toner powder of Australia can be used in asphalt mix, but many citizens are ignorant of this and they throw out their toner waste.

Figure 5-25: Re-surfacing using asphalt containing recycled printer toner (City of Sydney, 2015)

While 13% of toner cartridge is currently wasted, there is a need of about 100 cartridges of toners for every tonne of asphalt.

Plant Ark is collecting the cartridges of printers and the rate of the collection of the cartridges is sufficient enough to contribute to the production of over 100,000 tons of asphalt, whereas the total use of Asphalt by the roads of Sydney was 750,000 in the year 2014. There is also a possibility to import the waste from foreign countries to enable the uninterrupted production of Asphalt by recycled toners. The discovery of this technology was made owing to the fact that the powder of the toners can be stored in the form of pellets. This technology can be used as a better alternative than traditional asphalt and can also be used in countries outside Australia.

This technology that has been introduced by Toner Pave works by the toner material with the warm mix of the asphalt. The warm mixture of the asphalt is then heated to a temperature of about 20-50 C less than the temperature that is used for heating the regular asphalt, leading to the saving of 24,000 kg of the emissions of carbon dioxide every year.

Around 30% of this material is composed of asphalt that is recycled, which is much greater than the requirement of industry that states the requirement to a level of lesser than 10%.

Process of making the Toner Pave

In the first step of making the Toner Pave, the cartridges are sorted and then fed to the recycling lines. Then in the next step the separation of the Toner Powder, plastic, metal and other products are done in order to reuse them. The Toner powder from many sources is combined to form a bulk toner. There is a need for homogenising a variety of toners for the minimisation of variability. After the homogenisation, there is a need to refine as well as purify the toner and prepare agglomerate. The toner then prepared is mixed with additives and made into pellets. The finished product is known as Modified Toner Polymer. The MTP is supplied to many locations where it is needed for the construction of roads, after the addition of the MTP to the asphalt takes place. The added material is then supplied to the sites and they are loaded to the paving machine. Then the Toner Pave is applied to the roads (City of Sydney, 2015).

Economic benefits of the Toner Pave Material

The cost of this mixture is $150 per tonne, which is equivalent to the cost of the standard asphalt that is used for the construction of roads. The major costs incurred in road resurfacing are the cost of the asphalt whereas a smaller portion of this cost is covered by the raw materials used. The benefits such as reduction in the carbon emission outweigh the high costs of the materials.

Environment and sustainable Benefits of Tone material

This is a positive measure that can contribute to the significance of the reduction of greenhouses gases. Such a measure was undertaken by Sydney to reduce its greenhouse emission by 70% by the year 2030. This technology has been certified as carbon neutral by the National Carbon Offset Standard (Tan, 2015).

Energy saving - this technique is energy saving as the mix of the printer toner is heated to a temperature of less than 20-50 degrees than the regular asphalt that is used. This reduces the energy emission to a significant level.

Reduction of the landfill - by the use of used printer cartridges there are fewer printer cartridges that end up being a part of landfill. Around 20,000 tons of the waste cartridges have been recycled so far, since the beginning of this initiative in the year 2012, which is a very significant amount of reduction in the landfill.

Reduction of the crude oils inroads - by the use of the printer toner in the asphalt mix also there is a reduction in the amount of bitumen that is derived from crude oil.

Recycled asphalt pavements - the recycled asphalt pavement is a material that is made by processing and using the asphalt again and again. Before the discovery of this method, these materials were either made a part of the landfill or were down-cycled, which means recycling the material to a material of lower value.

Currently, the use of recycled asphalt in the city of Sydney for the construction of pavement content is about 15-20% as a part of the program for road resurfacing. By the use of the recycled pavement the annual savings that are brought in the emissions of carbon are also very significant (23,000 kg).

Process of making the Toner Pave-In the first step of making the Toner Pave, the cartridges are sorted and then fed to the recycling lines. Then in the next step, the separation of the toner powder, plastic, metal and other products are done to reuse them. The toner powder from many sources is combined to form a bulk toner. There is a need for homogenising a variety of toners for the minimisation of variability. After the homogenisation there is a need to refine as well as purify the toner and prepare agglomerate. The toner then prepared is mixed with additives and then it is made into pellets. The finished product is known as Modified Toner Polymer. The MTP is supplied to many locations where it is needed for the construction of roads after the addition of the MTP to the asphalt takes place. The added material is then supplied to the sites and they are loaded to the paving machine. Then the Toner Pave is applied to the roads (City of Sydney, 2015).

5.9 CASE STUDY 8: THE JET STREAM SUPER-HIGHWAY

This highway was designed by David Huang. The super highways are an innovative concept that is based on the vehicles that extract energy from the infrastructure of the roads and take energy from the environment (Huang, 2015). These highways have an open return design for the wind tunnels that leads to the production of a stream of air flow on a continuous basis. The shape of this roadway is like a half-pipe seen in a cross-sectional view. These highways are made up of a series of turbines that are powered by solar energy and they hover in order to push the air in the pathway of the road. There is a cycle effect formed by the drawing vents over the flanks as a result of air being drawn continuously. Owing to the lining of the solar panels at the upper road surface, this is a very environment-friendly green design. There are sensors that enable communication with the vehicles that are driven on the road, in order to get accurate adjustments. This highway is based on the concept that the future of the transportation in urban areas is based on implementing green techniques of energy usage as well as conservation.

According to David Huang the future of transport is the Jet Stream Super Highway. This is a method that would enable the integration of environment with transportation and construct self-sufficient roads that draw energy from the road itself instead of using the non-renewable sources of energy.

In the first part of this project comes the tunnel design that produces a continuous stream of flow of air from the surrounding environment. The shape of the roadway is like that of a pipe, as seen in cross-section. The road has solar powered turbines arranged in a series fashion that has turbines as well as fans that hover above, pushing the air in the pathway of the road. Also, the air is drawn continuously at a rate that is controlled by the aid of the vents as well as the flanks. The upper surface of the solar panel is aligned to the road and leads to the development of a fully green technology of construction. The roads have sensors that enable the communication by the vehicles that are on the road for the necessary adjustments to fine tune with the wind power

In addition to this, Huang's design also has Hyper Wing Sail Vehicles. This is a transport vehicle for the first generation that is powered by the wind. It is particularly designed in order to transverse the Jet Stream system. The vertical wing of the sail has dual foils that enable efficiency as well as control the flow of air properly. The outrigger wings and the rear wheels enable stability to the system when it is operated. The body of the system is designed in order to sustain and manage the laminar flow of air and has air as well as wheel brakes that can be used to bring the vehicle to a halt. After moving on the highway, the super green car is transformed into a mode that is compact and has motorised wheels and a battery.

Figure 5-26: Highway E-Turbines (Huang, 2015)

Figure 5-27: Turbines on the highway

This system of turbines on the road (above in Figure 5-27) is another innovative concept that is a brainchild of the designer Pedro Gomes. Also known as E Turbines, this a system of wind generation that uses the movement of the air that is dissipated from the traffic that passes, in order to accumulate as well as generate energy. The energy generated thus can also be used to light the street lamps as well as the traffic signals. These can also be used to operate emergency phones. These systems are placed between the lanes of the roads. These panels enable the generation of energy by storing the kinetic energy of the moving air generated by the movement of traffic on the roads (EcoFriend, 2011).

Economic benefits of the Jet Stream Super Highway

The economic benefits of this highway are still unknown as it is still a pilot project.

Environmental and sustainable benefits

This is an energy efficient method that would lead to the construction of self -sufficient roads that are not dependent on non-renewable sources of energy.

5.10 CASE STUDY 9: EME2 TECHNOLOGY

There is a challenge within the road construction industry to design and deliver asphalt materials of high performance to be able to carry high loads of traffic and the loadings of the axle wheels. With the increase in traffic in Australia, there has arisen a need for high-performance asphalt materials in order to cope with the changing scenario**.**The term EME has been taken from the French language 'enrobes à module élevé', which is known as 'high modulus asphalt' in common parlance. This technology is being used extensively in its country of origin i.e. France, as well as in other countries. EME is then again classified into two grades: EME Class 1 and EME Class 2. The difference between the two is that EME Class 1 has a higher binder content in terms of the richness modulus; on the other hand EME2 mixtures are based on richness modulus as well as upon the requirements for factors like water sensitivity, wheel tracking, stiffness and fatigues, and upon requirements for air void. The EME class 2 (EME2) is generally used in heavy traffic roads. The component that makes EME differ from the rest of its competitors is the high binder content grade bitumen, which is quite hard paving. The major characteristics of EME are it is comparatively more durable as well as stiff. It has a remarkable long durability factor as well. Another advantage of EME is that it also can decrease the pavement thickness without major change in the quality of the roads (Petho, Beecroft, Griffin, & Denneman, 2014; Petho & Bryant, 2015)

Approach followed in Africa and Australia to develop mix design specification

In order to compare the performance of EME between France and South Africa, a mix was designed that has the components of South Africa and then this mix was put to various tests and experiments according to French tests for checking its performance parameters. The tested mix was then designed in the CSIR laboratory again and thereby it was put to test in accordance with the local test methods.

In Australia, in order to test EME, a sample was sent to the APRB Laboratory in Melbourne. A bench mark was created using this French sample, which underwent equivalent tests in Australia in order to test its performance parameters. Also, the Australian samples were sent to France for testing purposes. The data so collected were then scrutinised by the Austroads.

The High Modulus EME2 mixtures are thermal damage-prone, which is a result of temperature drop and temperature variations and also thermal fatigue cracking. One of the effects can be attributed to the binder getting brittle at lower temperatures. These cracks can also be caused due to thermal volumetric change.

In France, in order to overcome this problem, EME2 mixtures are used in the base course in order to give it less exposure to changes in the temperature. Another way to avoid cracks it to insulate the EME2 layers. This could be achieved with the help of binder course layers.

To overcome this problem in the UK there is a comparatively softer binder used for the purpose of insulation ranging from 30/45 to 40/60 pen.

In Queensland, Australia, a collaborated effort of the Australian Asphalt Pavement Association, Australian Road Research Board, and the Brisbane Council have introduced EME2. The trial in Brisbane was a demonstrative effort which was conducted upon a local road that received traffic of around 30 heavy vehicles each day. There was the adoption of a more risk-oriented process which included the use of the EME2 on roads that were not heavily trafficked and on heavily trafficked roads in small sections for testing purposes.

In order to further provide for the use of EME2 there is PSTS107 made available. The PSTS107 is a pilot technical specification. This enables the users to have a broad idea regarding the mix of designs that were adopted in the test methods of Europe or Australia for testing the wheel tracking, fatigue, and flexural modulus. However, the test methods adopted in Australia are recommended only for low-risk ventures, as they are tested only on a small scale. For high-risk ventures, it is suggested to adopt the European methods. The interim method of pavement design is differentiated from that of the French methodology. The method used in Australia is based on varying pavement thickness designs. These are:

1. On the basis of traffic and subgrade support
2. On the basis of linking different characteristics of a mix.

One of the problems that is faced in Australia is that, due to a majority of short-term tests of the EME2, there are not many sources of local history to study, and hence the former method is used more extensively. Another advantage of using this interim method is its easy applicability in the Australian pavement designs framework, thereby facilitating comparison with the conventional methods.

The EME or the 'enrobes a module level' technology that was developed in France in the seventies delivers high performances of asphalt to be used in heavy duty pavements and is applicable for the situations as under;

- The pavements that carry large and heavy vehicles so that the pavements require extra strength in order to bring about protection to the layers that underlie them
- To bring about constraints for the thickness of the pavements in the areas that are urban such as motorways and the areas where there is a geometric constraint
- For the areas that have heavy influx of traffic like slow lanes, lanes for buses and pavement for airports, where there is a requirement to offer high resistance to limit deformation on a permanent basis.

Developed in France, the EME was based on the richness factor stated about the bitumen film. In the earlier times, the French practised two categories of the binder content based on their richness;

- One having a richness factor of greater than 3.2 inches, having a high content of binder this mixture category had high moduli as well as better resistance to fatigue
- One having a richness factor of between 2.5 and 3.2 inches, which is also known as lean mix; this mixture had a low content of binder and high moduli but limited fatigue resistance

In the phase of early development, a mix of 3.2 rich mixes was used and the mix that is accepted in the modern times is of a thickness of 3.4. The properties of the EME mix are as follows:

It has high resistance to deformation in comparison to the standard mixes that are being used.

The dynamic modulus of these mixes is high at 10Hz and at a temperature of 15 degrees Celsius it has a dynamic modulus of 14,000 MPa by the use of the two-point bending test.

There is a draw back too, owing to the high modulus that is at a rapid rate of cooling at low temperatures, where there is a possibility of thermal cracking. However, the experiences proved that there was no thermal cracking if the mixture of the EME was covered with a wearing course of asphalt, even in a very thin layer. Owing to the fact that the climate in France is temperate, the issue of the weather is addressed locally on the basis of the information of the weather.

The mixes of the EME can withstand fatigue and resistance up to 120-150 micro strain.

High Modulus Asphalt EME2 Pavement Design

EME was first developed in France over three decades ago. Now it is getting popularised in other locations such as South Africa as well as the United Kingdom. The main function of the High Modulus Asphalt is to reduce the thickness of the asphalt pavements that are of full depth while continuing to deliver better performances of the pavements via a combination of greater modulus as well as better fatigue, the resistance to moisture as well as deformation.

EME2 is more commonly used in roads that have high traffic influx. The EME2 technology is getting popularised in Australia too. The introduction of the EME2 in Australia is through an effort by the Australian Road Research Board, the Australian Pavement Association and the Brisbane City Council. The first trial of the use of the EME2 in Australia took place in Brisbane in the year 2014. This trial took place on a road that has an influx of over 30 heavy vehicles on a daily basis.

Australian EME2 Mix 1	AGPT test at 30 000 cycles (60 000 passes)		EN test method	
	Rut depth (mm) middle point	Proportional rut depth (%) middle point	French mix design Rut depth (mm) – using 100 mm thick slab	French mix design Proportional rut depth (%)
Average	1.63	3.3	1.5	1.5

Table 5.2: Australian EME2 Mix 1- results (Petho et al., 2014)

French EME2 mix, sample number	AGPT test at 30 000 cycles (60 000 passes)				EN test method	
	Rut depth (mm) Seven points average	Rut depth (mm) middle point	Proportional rut depth (%) Seven points average	Proportional rut depth (%) middle point	French mix design Rut depth (mm) – using 100 mm thick slab	French mix design Proportional rut depth (%)
2855	2.96	2.83	3.94	3.77	N/A	N/A
2888	3.64	3.56	4.86	4.75	N/A	N/A
Average	3.3	3.2	4.4	4.3	3.5	3.5

Table 5.3: French EME2 Mix 1- results (Petho et al., 2014)

Benefits of EME2

EME2 is uncompetitive for heavy duty roadways as compared to conventional asphalt pavement.

- Up to 30% cut layer thickness
- Allows heavier axle loadings
- Freight cost reduced
- Low structural maintenance
- Reduced traveller delays
- More sustainable in sense of renewable materials, energy and transport
- No effect of global warming on performance
- Less excavation for new pavements

Environmental / Sustainable benefits of EME2 technology

The EME technology is very apt for roads that suffer from deformation on a permanent basis and have a high stiffness, making it much better than the standard mixes that are used in the base layers at high temperatures. This mixture also is better resistant to fatigue to the high binder of the content mixture.

- Lasts longer, reduced thickness
- Uses less bitumen, aggregates, energy in production and freight
- Less disruption
- Able to carry heavier loads which decreases GHG emissions per tonne/km of freight

5.11 CASE STUDY 10: FOAMED BITUMEN STABILISED PAVEMENTS

Introduction - An initiative of the Austroads since July 2012, the project for testing the Foamed Bitumen Stabilised Pavement is to improve the procedures that are practised by Austroads in order to attain better structural bitumen for stabilised materials for building pavements that are new and also to conduct structural rehabilitation treatments. Also, the use of such pavements can enable the identification of the distress modes of bitumen and bring about improvement in the design of the national mix for the stabilised materials.

The objectives of the initiative for the research project taken on Mix Design and Field Evaluation of Foamed Bitumen Stabilised Pavements are

- Improvement of the procedures for Austroads for the design of materials that are new, and the pavement of structural rehabilitation and treatment of the roads
- This research is also oriented at the identification of the modes of distress of the FBS pavements
- Improvement as well as harmonisation of the national mixes design for Foamed Bitumen Stabilised materials

In order to better understand the process, the reference to Guide to Pavement Technology-Part 4D has been taken. There are two approaches that can be followed, namely the gyratory compaction method and the Marshall drop hammer method.

A mix design testing was conducted on the Newell Highway and the Calder Freeway

Moisture Content and lime type:

<u>Newell Highway Testing Procedure and its outcome:</u>

Fifty hammer blows were made following the Marshall Drop Hammer procedure. Also, the gyratory compaction method was used.

The moisture content is an essential factor that affects the density of the specimen road and it thereby also influences the modulus. It is essential that while determining the moisture content, care must be taken because a slight variation can affect the result of the entire assessment and also the stabilisation of the foamed bitumen thereby changing the entire result of the experiment.

Table 5.4: Impact on the density and modulus due to moisture (Austroads, 2015)

Compaction method	Moisture content (%)	Sample	Dry density[1] (t/m³)	Cured dry modulus (MPa)	Cured wet modulus (MPa)	Ratio wet/dry modulus
100 mm diameter Marshall	7.4	M7a	1.946	2730	740	0.27
		M7b	1.944	2980	900	0.30
		M7c	1.941	2930	940	0.32
	Mean		**1.94**	**2880**	**860**	**0.30**
	8.2	M8a	2.000	3430	1310	0.38
		M8b	2.029	3550	1620	0.46
		M8c	2.027	3570	1650	0.46
	Mean		**2.02**	**3520**	**1530**	**0.43**
	8.8	M9a	2.082	3820	1850	0.48
		M9b	2.078	3730	1940	0.52
		M9c	2.087	3730	1970	0.53
	Mean		**2.08**	**3760**	**1920**	**0.51**
150 mm gyratory	7.4	S7a	1.939	1760	580	0.33
		S7b	1.945	2250	940	0.42
		S7c	1.944	2240	1040	0.46
	Mean		**1.94**	**2080**	**860**	**0.40**
	8.2	S8a	2.037	3360	1490	0.44
		S8b	2.037	3350	1530	0.46
		S8c	2.043	3910	1730	0.44
	Mean		**2.04**	**3540**	**1580**	**0.45**
	8.8	S9a	2.075	3700	1800	0.48
		S9b	2.070	3630	1790	0.49
		S9c	2.067	3560	1890	0.53
	Mean		**2.07**	**3630**	**1820**	**0.50**

1 AS/NZS 2891.9.3:2014b Mensuration method.

Western freeway Testing Procedure and its outcome:

Upon investigating the western freeway sample regarding the performance of asphalt planning mixture, it was yet again concluded by way of the outcome that moisture content plays an important role on the density and the modulus.

Also, tests were conducted in order to find the impact of lime used in the mix design upon the moisture content, which led to the finding that the reduction in the density of the lime is the cause of nearly about half of the density reduction, hence while choosing the lime type, care must be taken as this can affect the end result because it plays a role in altering the module. In order to minimise the effect on the moduli, it is advisable to use hydrated lime (Austroads, 2013).

Mixing method and Laboratory compaction method

Mixing methods used:

The mensuration method:

- The specimens are assumed to be cylindrical
- The volume of the specimen is ascertained
- Also, the air void in the mixture is calculated.

The pre-saturation method:

- The bulk density of the compacted asphalt used as a specimen is ascertained by the amount of water that is displaced when immersed in water.
  The result of the above-mentioned methods used led to the finding that keeping the dry density constant the specimen with a larger diameter had a comparatively higher modulus than that compared with a lesser diameter. (Queensland Department of Transport and Main Roads , 2012)

<u>Compaction Method</u>

The specimens used in the Marshall and gyratory method were compared by way of fixing the number of cycles of the latter specimens for giving them the dry density similar to that of the specimens used in Marshall's Method (Austroads, 2011).

Table 5.5: Results of the compaction testing method, Source: Modified from (Austroads, 2015)

Compaction method	Bitumen content (%)	Lime content (%)	Moisture content (%)	Mean dry density (t/m3)(3)	Mean dry density(4) (t/m3)	Mean indirect tensile modulus (MPa) at 25 °C	
						Cured dry modulus(1)	Cured wet modulus(2)
TMR testing (150 mm diameter specimens)							
Marshall hammer 9.92 kg hammer	3.0	2.0 (hyd. lime)	7.1	–	1.99	2720	1090
Gyratory (Servopac)	3.0	2.0 (hyd. lime)	7.1	–	1.98	1110	480
Downer testing (100 mm diameter specimens)							
Marshall hammer 4.54 kg hammer	3.5	1.5 (quicklime)	7.7	2.11	–	2570	1710
Gyratory (Servopac)	3.5	1.5 (quicklime)	7.7	2.11	–	2220	1390

1. *Cured unsealed for three days at 40 °C.*
2. *Soaked in water under a vacuum of 95 kPa for 10 minutes at 25 °C.*
3. *AS/NZS 2891.9.3:2014b Mensuration method.*
4. *ASTM C642-13 similar to AS/NZS 2891.9.2:2014a Presaturation method.*

Foamed Bitumen Stabilisation (FBS)

For conducting this testing operation, a construction of two bitumen content mixes was done. Following this, the foaming capacity was also scrutinised. After mixing the sample with the foamed bitumen and before they were subjected to the compaction process, their samples were taken and the bitumen content already existing in them was also calculated before it was subjected to the foamed bitumen treatment. Also, samples were taken before the lime treatment and the foamed bitumen treatment. All the samples collected were then subjected to the ignition oven method.

- The result of this procedure was the conclusion that due to the lack of uniformity in the bitumen content already existing in the sample before foaming it is unreliable to estimate the amount bitumen to be added in the testing procedure. In order to test the FBS mixes according to their field performance, it is necessary for the testing to be conducted on the roads which have a quantified heavy vehicle loading.
- Monitoring the performance of the construction is a necessary step and the Falling weight deflectometer (FWD) test of the base used in the FBS should be undertaken the next month of the construction in order to check the level of deflection and the curvature.
- The thickness of the FBS layers was measured after one month of the construction. Due to the low strength of the FBS layer at the premature stage at some places, the FBS layer was not recovered at all.
- The impact of the pre-saturation and mensuration method was assessed. In the Calder Freeway, a 5 % reduction was observed between the top and the bottom halves.
- The roughness and the rutting of the construction were on a lower scale and if any of these took place; it was due to the constructed shape.

Performance of the construction:

It was predicted that the chance of FBS cracking in 3-4 years could be about 50% (Austroads, 2012).

Summary of FBS pavements

After evaluating several Austroads mix designs as well as FBS pavements, it was concluded that several improvements are required.

Various test methods were used, which are listed below:

- The bitumen foaming property-determination
- Mixing of the FBS materials
- Compaction Method and the Gyratory method
- Resilient Modulus of the FBS
- The wheel tracking test method
- In was also concluded that there is a need for the Marshall drop hammer testing method.

Findings:

- It was observed that dry density has a major impact of the indirect tensile moduli.
- The density is one of the essential factors that determine the modulus. The number of loading cycles can also be adjusted by using the gyratory method. The in situ dry modulus-density can hence be adjusted as per the requirement.
- Also, the moisture content is another determining factor. However this, when mixed along with foamed bitumen and the put-under-compaction process, may lead to inconsistencies. The difference in the moisture content can become the cause of change in the specimen density and also in the modulus.
- Another finding was that due to the use of varying methods of measuring density, the result may cause complication in the modulus adjustments. The pre-saturation method results in a 2-3% more dry density as compared to the mensuration method. Hence, in order to bring consistency to the density, it is necessary that a uniform approach is used.
- The result of the use of the gyratory compaction method proved that the mix modulus of the sample with a larger diameter was more as compared to the one with the smaller diameter. Hence, the one with the larger diameter was preferred.
- After conducting a comparative study between the samples used in the Marshall Hammer process and the one that was used in the Gyratory compaction it was found out that the later one had a comparatively lower modulus as compared to the former one. It was agreed that the Marshall Hammer method would be adopted in the mix design assessment conducted in the laboratory.
- Upon comparing the hydrated and the quicklime used in the mix in different samples, in was seen that the moduli which were extracted using the hydrated lime

were two times the value of the quick lime moduli. Because of the moisture consumption in the process of slaking the quick lime, the density of the quick lime specimen was up to 3% less as compared to the hydrated lime sample.

Testing of the field –mixed

There are certain differences in the result of testing the field mix material due to the time interval in compaction of the material after the mixing procedure is complete; this directly has an impact on the Maximum Dry Density. Hence, there is a need to adjust the time delay.

The improvement in the thickness design

This was one of the objectives of this project. In order to improve the thickness design, it is assumed that the FBS material cracks like a hot mix asphalt having low binder content. To ascertain cracking, two cores were obtained with a similar binder content, of which cracking was detected in only one, hence it can be concluded that fatigue cracking is only suggestive in nature. Dry modulus is suggested to be used in areas with low rainfall. In order to improve the fatigue performance, it is important to perform comprehensive laboratory research. (Austroads, 2014).

5.12 CASE STUDY 11: PLASTIC ROADS

The Netherlands is doing a pilot study of making a new kind of road that is much more reliable and easy to lay, using recycled plastic. The country already has roads (more precisely, a bike lane) that can generate electricity. In fact, they are the ones who have the world's first solar roads (Koudstaal & Jorritsma, 2015).

Roads will be completely made from recycling plastic. They will tolerate much more temperature variation and need less maintenance too, as compared to ordinary asphalt roads. Furthermore, the Construction Company named Volker Wessels reveals that those kind of roads are very easy to make and have three times more life than ordinary ones.

The company also claims that it's not only faster to lay road but it also gives an easier pathway for cables and pipeline for utility purposes.

According to an environmental study, 2% of all road emission i-e, 106m tons of CO_2 emission, is because of asphalt, which also can be overcome in this situation.

Figure 5-28: Plans unveiled for recycled plastic roads (Koudstaal & Jorritsma, 2015)

Volker Wessels is Construction Company from Netherland, and they are first who give first awareness about plastic roads. They said that roads made up of plastic would be "virtually maintenance free product" as weather and corrosion would not affect much. Road will be good in cold as -40 and also can handle extreme temperature like 176°F. The company also said that road will last long than ordinary road because of its hardiness.

Simon Jorritsma who works in infraLing section of firm, (which works on asphalt specially) said that, when company faced many problem by asphalt road like flooding and road repair within city, also decrease in availability of oil in future develop the idea about plastic road.

The PlasticRoad durable compared to asphalt roads.

We assume the longer life of roads made of plastic to be at least 50 years; this calculation is done by keeping the life of plastic pipelines that are being used for sewage and water purposes in mind.

The key benefits of the PlasticRoad

- Time-saving in faster construction
- Better duration of life (homogeneous and prefab)
- Less repairs because the material is very resistant to different weather and weeds.
- The innovation is green as the material used in this is completely recycled.
- Hollow design gives easy space access for pipeline and cables.
- Lightweight.

Concerns about plastic road

Noise

Defiantly road made up with plastic have better prospects in context of noise reduction. We are making ideal structure in asphalt to reduce noise but this structure could be created with plastic at ease. This whole idea of reducing sound can be achieved just by printing structure into plastic.

Feasibility

Volker Wessels is making a considerable investment in the research of plastic roads as they trust that the idea is feasible. Further research will unveil whether this idea can be implemented or not.

Slippery conditions/ wintertime

Plastic can be more slippery compared to asphalt; this can be overcome by making the plastic surface more rough. Some ideas are to press crushed stones on the surface or a sand surface can be printed on the top surface. These can make plastic skid resistant, especially in winter time.

Sustainability

KWS Infra is talking sustainability issues as a major risk; they are studying at what level damage can occur, and what are the problems that can occur because of those free particles of plastic. A coating layer can overcome this problem, and they are looking for the most durable possibility.

Plastic can be toxic after catching fire, but to what extent it will release injurious element, research still has to be done. A fire resistant coating can be used to overcome this concern. At the first stage, this kind of road is only built for bicycle paths, where fire concern is significantly very low.

The plastic that has been used in this is 100% recycled material, in fact because of burning the plastic again and again, this changed its chemical chain and reduced the carbon footprint. As plastic road is placed directly on sand surface, there no need of foundation, and this means less of a need for heavy construction on site.

5.13. CASE STUDY 12: BAUXITE RESIDUE – RED SAND AND RED MUD

In Australia the way of building and construing roads and their infrastructure may face several challenges over the next few years of time. Challenges include the substantial number of promptly growing economies from all over the world, important changes to global and local weather patterns and life-threatening weather measures, and forecast growths in two main areas prices of used recourses and energy (Evans 2011).

Figure 5-29: Re-Sand Bauxite Residue (Evans 2011)

Moreover, prominent efforts from all over the world are now presenting how and from where these challenges of constructing roads can now be encountered with the help of innovation and creativity through numerous features of constructing roads. The leading message emergent from these action and efforts is that the changes are there to renovate the way in which currently construction of road infrastructure is constructed and conceived, to contribution civilization in order to reply to decrease a range of ecological pressures and climate change. Therefore, sustainability is constructing roads is important.

Figure 5-30: Bauxite Residue in Road Construction (Evans 2011)

As Australia plays an important worldwide role in contributing in natural resources and minerals for international markets. The consistent challenge of this unexpected market strength is the required to recycle, reuse, and storing products by toxins and product name. This naturally includes process residues and mine tailings. The usually accepted reply in Australia is to residence the investigations and remainders in caused loading facilities, active organization, requiring long-term. Though several countries, such as Denmark, Sweden and Germany are situation guides by attaining high rates of recycle of their manufacturing wastes. For example, Australia goods 40% of the world's alumina with numerous alumina plants situated nearby population centres.

Figure 5-31: Re-Sand Bauxite Residue in Road Construction (Evans 2011)

In addition, Australia presently stores, forty million tonnes per annum of bauxite residue from the alumina trade; 14 million tonnes per annum of ash from power stations of coal fired.

Case Study – Australia "ReSand" Bauxite Residue in Road Construction

The idea called Re-Sand developed by The Centre for Sustainable Resource Processing (CSRP) in Western Australia. Where sand sourced from improved bauxite filtrate is utilised in place of unadventurously sourced excavation sand with correspondent performance. CSRP commenced a demonstration research project with major roads in Western Australia, containing of numerous hundred metres of sub-base for one track of a brand new link road that connecting Perth to Bunbury Highway with Pinjarra area.

This research in the area of constructing road carried out by the university Curtin and Alcoa which is recognized a parting process for by means of the coarse quartz, module, in Re-Sand. Laboratory doing this testing in 2006, which shows that Re-Sand could offer commercial majority fill and roadway material for the public building industry, substituting the usually used limestone and sand.

Initial in the surveys, the sand properties which are physical were studied through Main Roads and the study results analysed its site in the road expert file. In this research project the sand case was used in place of crumpled mineral in the layer which is sub-base. The road construction trial elaborated the Queensland University, many other Consultants and Services which provided by Southern Roads, the contractor accountable for distributing all conservation and slight construction works in the public road system for the Western state of Australia.

Re-Sand met all regular industry conditions for constructing road base tenders. It has slight if any sand, has countless wetting properties and drainage, needs only light arranging, and contracts well. The presentation of the road-way is presently being watched by Main-Roads in regard to assess the following:

- The influence drainage water on surface
- The relative performance of the Re-Sand unit and a normal road section with respect to ground water and surface
- Up and down streams observing contrasts in light of water guidelines
- Comparative valuations of presentation, and evaluation of future trials.

5.14 SUMMARY

The case study section has enabled providing a view of the recent innovation in terms of technology, use of new materials, environment-friendly methods, and methods that decrease the budget requirement as well as the time that is taken to build roads, making the construction process more efficient. This chapter also shows that Australia is adopting innovation as a measure to increase the efficiency in road construction and maintenance. But in respect of the better practices that have been adopted across the globe, there is a need to integrate more successful innovation that exists globally. The road construction sector has become much more environment-friendly by adopting greener methods of road construction as well as maintenance. There is the developer of the self-sustained solar road as well as the highway in the Netherlands that glows in the dark. These roads do not depend on renewable sources of energy for their energy requirements. Also, the use of recycled materials such as the industrial waste and the recycled asphalt use in Hamburg, Germany, are environment-friendly practices that lower the pollution levels as well as the land load. These web-enabled technologies have made the road construction process more automated and with better-managed databases.

Table 5.6: Summary of the typical innovative practices from case studies (developed by Pardeep Kumar Oad)

	Case Studies	Location where used	Driving factors	Economic Benefits	Environmental / Sustainable / other Benefits	Barriers
1	**Use of 100% recycled asphalt Using recycled industrial materials in Roadways**	**Hamburg Germany**	Cost efficiency as the price of the road surface materials such as bitumen has increased significantly	• The use of this method could save 30% of costs than compared to the conventional costs • (Innovation Seeds, 2012)	• Effective method to reduce the environmental overload as well as pollution and also leads to the effective use of non-renewable resources • Energy conservation and decreasing the amount of emissions of Carbon Dioxide as well as other harmful gases • less energy usage • This led to saving of costs and complying with the policy of using recyclable materials for road construction	The barriers to the project: There is a need to understand and adhere to the waste management techniques and regulations in order to implement this project.
2	**The innovative eco-friendly road solution by Innowattech**	**Israel**	Harvesting the waste kinetic energy and using it to generate electricity. The method is very easy to use and not very costly	• The cost of installation of these systems is lower than the installation cost of either wind or solar systems. • This method can reduce the usage of the non-renewable sources of energy for the generation of kinetic energy leading to a tremendous amount of cost saving. It can save up to 80% of energy generation costs and provide employment opportunity further increasing the economic benefits (Probst, et al., 2013)	• They give a constant supply of electric energy to the roads irrespective of the condition of the weather. • This is a system of electric energy to the roads that is both Foolproof of theft and damage	However, there is need of electric energy system to the roads that is both Foolproof of any theft and damage.

Continued

	Case Studies	Location where used	Driving factors	Economic Benefits	Environmental / Sustainable / other Benefits	Barriers
3	**Solar roads**	Netherlands France (Wang, 2016) USA	The driving factor for the technology of solar roads is the need to build a road that conserves energy and is self- sufficient. Also, the construction of roads that just cannot sustain its own energy requirements but provides energy to the nearby households	• Leading to the creation of many new jobs • A mile of a solar road can produce energy enough to provide power to about 500 houses • Cheaper energy (Solar Roadways, 2015) (Sola Sign, 2015)	• Reduction in pollution • the decrease in the dependence of conventional energy sources such as fuel and coal • These initiatives will enhance the economic conditions • Reduce the shortage of power and the dependency on foreign oil • These roads would not emit any greenhouse gases (Green Energy, 2015). • These road projects can be customised in accordance with the geographic location • Solar roadway with a heating system to automatically prevent the snow layering in the roads. With the use of LEDs in the roads there can be lighting achieved in the roads (Green Energy, 2015).	• These roads are very costly as one solar panel costs as much as about 7000$ and there is the requirement of billions of such panels for the construction of the entire road • There is a need to spend lots of time as well as money for the installation of these roads • Also, the construction of these roads requires the training of the members of the crew • The time taken by the electricity generated by these roads to cover up their cost of construction is quite high (George, 2015)
4	Futuristic highways in the Netherlands glow in the dark	Netherland	The creation of highways that are interactive and sustainable in nature.	• The economic benefits of these roads are associated with the amount of energy that can be saved by permanently shutting of the streetlights by the use of the glow in dark roads. In the year 2011 when the street lights of England were shut off for a night to	• The roads are more efficient and less accident prone • Lead to the development of an internal system of navigations	• Conserving energy as these roads can replace the street lights • As this is still a test project there is a need to address certain issues pertaining to these roads such as the high costs of the paints and also the

Continued

	Case Studies	Location where used	Driving factors	Economic Benefits	Environmental / Sustainable / other Benefits	Barriers
				reduce the carbon emission, there was a net saving of $668,000 of money. So the use of these roadways can mean $1,337,000 annual spending if only one-third of UK's street light are shut for a certain time duration or they are dimmed (Mac Donald, 2015).		durability of these products and their environmental implications
5 6	SCATS (Sydney Coordinated Adaptive Traffic System) Information and Communications Technology (ICT) **The moveable barrier system** The Continuous Flight Augur (CFA) pilling	Sydney, Australia	The traffic increases to a level that requires the vehicles to stop at many places before a congested link is cleared	• The average cost of purchasing a transport and a transfer machine is around $ 650,000. The cost of the barrier is around $500 for every metre block. The total cost of the barrier for one mile comes to $800,000. There have been surveys conducted in which the respondents have stated about the benefit to cost ratios - it was 2.2:1 in Boston and 6.5:1 in Dallas (Bain, 2000) (Colyar, 2001), (Geers, et al., 2009)	The system works in a method that enables the estimation of the queue length on the basis of information via upstream loop detectors. This system enabled the detection of traffic delays especially at the time of greatest traffic congestions.	• The project is costly making its implementation difficult for low budgeted construction programs which are one of the prime barriers of the project
7	Precast Pre-stressed Concrete Pavement (PPCP)	U.S.A	The method came up with an efficient solution to attain rapid construction of the roads that are durable and does not disrupt the normal flow of traffic for long.	• Reduces the time of construction and improves the road durability which in turn leads to the reduction in the costs • According to a study in America around $41 billion is spent per year on repairing the vehicles owing to the bad	• It has the futuristic prospect of increasing the season of construction of paving the roads. The casting and the curing of the precast prestressed pavements are done in an environment that is controlled leading to the continuation of the construction of the pavements	Innovative methods and using techniques of road construction at a rapid speed without disturbing the normal flow of traffic.

Continued

	Case Studies	Location where used	Driving factors	Economic Benefits	Environmental / Sustainable / other Benefits	Barriers
				conditions of the roads. The PPCP being more durable and smooth significantly lowers the costs of vehicle repair. • The system provides quick rehabilitation and reconstruction that is durable. Also, the higher costs of the system are a negligible offset considering the quick installation that reduces the closure of the lanes for longer time period. • Highly consistent having a superior uniform quality (Merritt & Tyson., 2006)	even in the adverse conditions of the weather whereas the normal pavement construction gets severely impacted in adverse conditions of the weather	
8	**Toner recycling for roads**	Australia 2015	The roads are being built by the use of old computer toner cartridges. Using the computer toners as an adhesive material is a very effective concept as using green asphalt leads to the reduction in the emissions	• Reduction in the carbon emission outweigh the high costs of the materials (Rowley, 2002).	• Sydney to reduce its greenhouse emission by 70% by the year 2030. • Energy saving - this technique is energy saving as the mix of the printer toner is heated to a temperature of fewer than 20-50 degrees than the regular asphalt that is used. This reduces the energy emission to a significant level. • Reduction of the landfill - by the use of the used printer cartridges there are fewer cartridges of the printer that are ended up being a part of the landfills. Around 20,000	This technology needs to be circulated and popularised as the entire wastage toner powder of road construction industry, which can be used in the asphalt mix but many citizens are ignorant and they throw their toner waste.

Continued

	Case Studies	Location where used	Driving factors	Economic Benefits	Environmental / Sustainable / other Benefits	Barriers
					tons of the waste, cartridges have been recycled so far since the beginning of this initiative in the year 2012 which is a very significant amount of reduction in the landfill. • Reduction of the crude oils in roads - by the use of the printer toner in the asphalt mix also there is a reduction in the amount of bitumen that is derived from crude oil	
9	The Jet Stream Super-Highway	Industrial designer David Huang	The method that would enable the integration of environment with the transportation. This is energy efficient method that leads to the construction of self -sufficient roads that are not dependent on none-renewable sources of energy.	• Still unknown as it is still a pilot project (Huang, 2015)	• This is energy efficient method that leads to the construction of self -sufficient roads that are not dependent on none- renewable sources of energy	This is method only use in the transport vehicle for the first generation that is powered by the wind
10	EME2 Technology	Origin in France, Now a days adopted by S.A, UK and Australian	The method can decrease the pavement thickness without changing the quality of the roads much	• Decrease the pavement thickness • High resistance to deformation on a permanent basis (Corsi, et al., 2004). • Freight cost reduced	• More durable as well as stiff • Last longer, reduced thickness • Use less bitumen, aggregates, energy in production and freight • Less disruption	There is a need for high-performance asphalt materials in order to cope up with the changing scenario

Continued

	Case Studies	Location where used	Driving factors	Economic Benefits	Environmental / Sustainable / other Benefits	Barriers
		(Brisbane in 2014)		• Less excavation for new pavements	• Able to carry heavier loads which decrease GHG emissions per tonne/km of freight •	
11	Improvement in Technology, Foamed bitumen stabilised pavements (FBSP)	Australia (Austroads, 2014).	It is essential that while determining the moisture content, care must be taken because a slight variation can affect the result of the entire assessment and also the stabilisation of the foamed bitumen thereby changing the entire result of the experiment.	• Procedure improvement • Moisture content detection	The use of such pavements can enable the identification of the distress modes of bitumen and bring about improvement in the design of the national mix for the stabilised materials	Improvement of the procedures for roads for the design of materials that are new, and the pavement of structural rehabilitation and treatment of the roads
12	Plastic Roads (Pilot study)	Netherland (Koudstaal, 2015)	Improvement of the procedures for the Austroads for the design of the materials that are new and the pavement of structural rehabilitation and treatment of the roads	• Faster construction • Less maintenance	• Longer lifespan • The innovation is green as the material is used in this is completely recycled. • Hallow design it gives easy space excess for pipe line and cables. • Lightweight	However, the moisture content is an essential factor that affects the density of the specimen road and it thereby also influences the modulus. This is the drawback of this system

Continued

	Case Studies	Location where used	Driving factors	Economic Benefits	Environmental / Sustainable / other Benefits	Barriers
13	Bauxite residue – red sand and red mud	Evans (2011)	The way of building and construing roads and their infrastructure may face several challenges over the next few years of time.	• The influence drainage water on surface • The relative performance of the Re-Sand unit and a normal road section with respect to ground water and surface	• Up and down streams observing contrasts in light of water guidelines • Comparative valuations of presentation, and evaluation of future trials.	Challenges include the substantial number of promptly growing economies from all over the world, important changes to global and local weather patterns and life-threatening weather measures, and forecast growths

Chapter 6 : Analysis and discussion from table 5.6

In this section the data that is gathered from the sources of multiple case studies will be processed as well as sorted on the basis of the types of innovation that are being adopted in the sector of road construction, such as the use of new and innovative materials, adoption of better techniques of construction, operation as well as maintenance in the construction sector. The identification of these case studies will lead to the process of data in terms of reduction of costs, as well as benefits that the road construction authority can receive by the use of these methods. This chapter will indicate the research outcomes in terms of the best innovative practices in the sector of road construction, as well as their feasibility of being adopted by the road construction industry. As the analysis of the case studies is not simple, the strategy that will be used for this study is the use of the propositions in order to encapsulate the objectives of this study leading to form the important basis of the data collection. Also, a descriptive framework for organising the case studies that have been used will be adopted (Rowley, 2002).

The case studies result shows that many sustainability initiatives assisted reduce the ecological pressures produced by many projects in the area of constructing roads. For the road bears, rather than using the conservative concrete piping, 100 % cent reused high thickness polyethylene piping were used. This assisted in decreasing overall cost, as well as dropping connection time by 55%t. On location, up to four millimetre of storm-water was taken and employed to overpower the dust everywhere the work location in order to decrease the contaminating of the nearby area. Only in Australia recycle 89% of road construction waste and, with the usage of re-cycled blacktop and save around 8500 tonnes of raw-materials when constructing roads. Additional key option was the road construction of one of the major bio retention sinks, casing 600 meter to utilised storm-water extra from 4ha of Australia roads. In road construction industry, the material called “Portland cement” is frequently used. With each tonne that produced Portland cement, in which one tonne of carbon-dioxide is emitted. Hover ash was employed as a supernumerary for cement, which save around 200 tonnes of carbon.

This research has enabled the finding that, in order to implement and integrate successful innovation in the road construction sector in developed and developing countries, there are potential benefits in using a holistic approach that stresses on the technologies that are being used, the methods, the association and the collaboration between the authorities that are involved in the road construction as well as the use of better surface materials that require low maintenance in comparison to the traditional surface materials that are being used. This research also suggests that there is a growing need to adapt sustainable techniques of production and implement green production in order to reduce the emission of greenhouse gases in the process of construction as well as maintenance of the roads. Use of recycled materials in the construction of roads like the Toner Pave is a very smart technology to eliminate waste deposition as well as the production of sustainable roads that are environment-friendly in nature. Also, there seems to be a growing trend in roads being self-sustained and not depending on any external source for their requirements, such as lighting the street as well as the traffic posts. These roads can be used for added efficiency as they can also supply energy to the adjacent households and reduce dependency on non-renewable sources. This could also provide a source of earning towards the maintenance of the roads. After analyzing the different case study on solar road, it appears that Israel's solar road techniques and practices are the better than other.

6.1 PONTENTIAL BENEFITS FOR ROAD CONSTRUCTION INDUSTRY

The road construction industry in the world currently is using recycled material, which has been proved to be a very effective method to reduce the environmental overload as well as pollution and also leads to the effective use of non-renewable resources.

Just like the policy that has been adopted in Hamburg, Germany, that states that the roads in Germany will be repaired only by the use of recycled materials and the construction of roads by recycled materials such as fly ash, as practiced in France for the reconstruction of bridges.

Some developed countries such as Germany, France and Australia are using an older innovative method such as recycled computer toner cartridges as a material for building roads. Another very effective innovation method can be to use waste cartridges from printers to replace the asphalt that is used for the building of roads, leading to a reduction in the emission of greenhouse gases to up to 40%.

This recycling innovation needs to be popularised all over the world as it is a very eco-friendly method leading to a reduction in the waste overload of the environment as well as control in the emission of greenhouse gases. There is a need to popularise the collection of waste cartridges at places or separate boxes in the town so that the waste cartridges get utilised and are not thrown away. Making road building material by this method requires a production process that is less than up to 20-50 degrees than the traditional method leading to a significant reduction in the energy. Also, popular practice of this method in the future would lead to the reduction of landfill in many countries.

The use of industrial materials as a replacement for non-renewable products that need mining as well as processing has become a very common and abundant phenomenon. This leads to the conservation of natural resources as well as to the reduction in the usage of energy and pollution that is a by-product of mining and producing these materials that used in the construction of roads. Most of the developed countries' road construction authorities are implementing the use of pulp, paper and other industrial wastes such steel and slag for road embankments. This will lead to improving the soil texture as well as reducing the runoff.

Also, mechanically stabilised earth walls can be used, leading to a reduction in the soil erosion. There can be the use of the fly ash collected from blast furnaces to partially replace Portland cement, for greater durability as well as the strength of the roads. The bottom ash can be used as concrete aggregate; sands from foundry, concrete that is reclaimed and slag from the blast furnaces could be useful in this type of situation.

Portland cement can be made by mixing it with fly ash, FGD, gypsum, sand from the foundry, slag, and steel. The slag from the blast furnaces and from the boilers can be used in place of the virgin aggregates that are used in the surface layer of asphalt. The base layer of asphalt can be replaced with bottom ash, sand from the foundry; concrete that is reclaimed mixed with asphalt can be used as an aggregate instead of the base layer of pure asphalt.

The case of San Francisco Bay Bridge Reconstruction is a successful example of the use of industrial by-product and recycling it for building roads as well as the construction of bridges. This strategy is also implemented by different road construction firms leading to the sustainable and environment-friendly construction process of roads by the use of materials such as fly ash as well as the granulated ash from the blast furnaces in order to enhance the strength as well as the durability of the concrete that is used. This project used the chemical properties of fly ash concrete in order to cover up the negative effects of the sea water and salt fog that has corrosive action, as the structural requirement of the earthquake zone (The United States Environmental Protection Agency, 2012).

Mechanically stabilised earth walls can be used, leading to a reduction in the soil erosion. Fly ash collected from blast furnaces can partially replace Portland cement providing economy in construction.

6.2 USE OF RECYCLED MATERIAL IN ROAD CONSTRUCTION

The use of recycled materials in the construction of roads all over the world can be a very cost-effective strategy as it would lead to reduction in the cost of construction to the economy, as the products that are used for the road construction such as bitumen are costly with the price increasing at a high rate. The use of recycled material is not completely being followed in Germany, France and Australia. Therefore, these countries can implement the method that has been successfully followed by other developed countries, which is the use of 100% RAP and stipulating asphalt at low temperatures.

These recycling methods are also environment-friendly in nature, as they would enable the road construction industry to tackle issues such as global warming and climate change, which are the major issues that Australia is facing currently.

The recycling methods that road construction industries can implement are as follows:

- Hot in-place recycling
- Cold in-place recycling and
- Full Depth Reclamation

Materials

The analysis of the case studies has indicated that road construction countries can use certain innovative materials in order to improve the present state of the roads. Moreover, the implementation and use of culverts is an efficient and effective method for road drainage. The use of recycled materials in the construction of roads all over the world can be a very cost-effective strategy as it would lead to reduction in the cost of construction to the economy, as the products that are used for the road construction such as bitumen are costly with the price increasing at a high rate.

6.3 TECHNOLOGICAL ADVANTAGES FOR ROAD CONSTRUCTION INDUSTRY

There is a need to research on advanced innovative technology in order to construct better roads that are sustainable in nature and benefitting to the environment as well as eco system.

The innovative eco- friendly roads technology developed by the Innowattech Firm in Israel can be implemented in other countries. This technology enables the harvest of waste kinetic energy. It uses piezotech generators to convert the kinetic energy that is generated as a result of the motion of vehicles in the roads in order to convert it into electric energy. The electric energy generated thus can be used to light the roads as well as the traffic signals. The use of this system would enable a constant supply of electric energy to the roads irrespective of the conditions of the weather (Probst, et al., 2013).

The use of solar roads is another innovative technology that can be used in the road construction industry. For example, this technology is being successfully used in the Netherlands. These self- sufficient roads can just not provide electric energy to light them but also can generate electric energy to light the nearby households. Although the initial construction costs of these roads are high, the economic income generated by these roads by the generation of electricity can be used to cover up their initial cost of installation as well as their maintenance (Green Energy, 2015). This will enable the road construction industry to reduce the emission of greenhouse gases by up to half of the current level that is generated by the combustion of fuels to generate electricity for the roads.

A solar road is a green alternative to burning fossil fuels in the generation of energy and electricity. These roads use the energy from the sun, which is conserved and transformed into electric energy.

EME technology can be used for the production of asphalt that is high performing in nature. This asphalt will be able to carry high traffic loads. This technology is being used extensively in its country of origin i.e. France, as well as in other countries. EME is then again classified into two grades: EME Class 1 and EME Class 2. The difference between the two is that EME Class 1 has a higher binder content in terms of the richness modulus; on the other hand EME2 mixtures are based on richness modulus as well as upon the requirements for factors like water sensitivity, wheel tracking, stiffness, fatigues and air void. The EME class 2 (EME2) is generally used in heavy traffic roads.

The use of the Futuristic Highway that glows in the dark that is a test project of the Netherlands is still questionable in Australia. This is because it is a future concept that requires more testing before being applied. These roads can enable a significant reduction in accidents. These roads will be equipped with modern technology such as the use of the internal system of navigation in connecting automobiles. This is a very efficient project that can lead to the construction of special roads that glow in the dark and can indicate the road directions to the commuters and can also enable the indication of weather conditions. The issues pertaining to this project such as high maintenance costs, and the uncertainty regarding the durability of these paints, needs to be tested before adopting this technology in the road construction industry.

6.4 OTHER MATERIALS FOR ROAD CONSTRUCTION INDUSTRY

Precast Pre-Stressed Concrete Pavement that is being used in the United States of America can be used in other developing countries in order to improve efficiency and effectiveness. These pavements can enable the construction of roads at a rapid rate and also the roads are durable in nature. These pavements enable the movement of traffic as well as the repair of roads. The components of these roads are assembled as well as fabricated somewhere else, then these components are installed in the pavement that exists. The use of this technology can lead to the easy and much more efficient construction of new lanes on the roads as well as the repair of the roads without causing disturbances in the traffic. The use of this system will enable the quick rehabilitation of the roads that are durable in nature. Although this system’s costs are higher, the benefits of this system, such as quick installation and durability, offset its higher costs as it requires less maintenance in comparison to the traditional system of road repair.

These prestressed, as well as precast pavements, are more durable in nature as they are put under compressive strength that reduces the cracking in the pavements. The use of this system reduces the maintenance of the roads to a great extent and this can be very cost effective for use in any road construction industry. Foamed Bitumen is better than structural bitumen for stabilised materials that can be used to build new pavements as well as for structural rehabilitation treatments. These pavements can enable the identification of bitumen’s distress mode, leading to improved designs for the stabilised materials.

Chapter 7 : Conclusion and implications

The rise in the technological knowledge of road innovation in the context of road material and roads, and the increasing exchange of knowledge among different developed countries around the world, offer new possibilities and promises for asphalt roadway communities. These will assist the wider realisation of innovative goods used in all selected countries to attain a technical and cost-effective optimisation of road administration and supervision.

This thesis has led to an in-depth study of the innovative practices that are adopted in the field of road construction in many countries by the help of various case studies that discuss successful road innovation, as shown in Table 5.6. This thesis has stressed the importance of road networks for the successful development as well as globalisation of any economy. Study results also found that at present, where there are predictable agreement relationships among road contractors and road authorities, this process requires a trustworthy structure for conveying goods between countries, and to give self-assurance concerning the claimed presentation quality. Each party should have its responsibility and parties must respect each other. The public road authority has its specific public function and the road contractor has to care about his specific industrial economical basis.

Moreover, the road network is very important for connecting one place to another, leading to the transfer of ideas, processes and technology. For example, most of the developed countries have a vast road network, so the need of sustainable development and maintenance is very important, as shown in Table 5.6. The thesis also indicates that the rising pollution and environmental challenges pose a requirement to use environment-friendly methods of road construction, as the burning of fossil fuels as well as the use of non-renewable sources of energy for the road construction, maintenance and movement of the roads, contribute to environmental degradation to a large extent. Result also found that constructing road in the context of reducing environmental impacts and designing optimise the alignment. It is worth importance that constructing road is integrally an well-organized practice that pursues to decrease costs connected to road construction and road maintenance.

In conclusion, in Australia for innovation in road construction industry mostly developer considers the flooring factors as important: recyclable material, sustainability of roads, climate change, resource scarcity and sola road. Moreover, there is a need for implementation of road innovation for every country around the globe. Therefore, innovation needs to be diversified and the successful innovation that has been practiced in one nation needs to be popularised and checked for feasibility and adopted by another nation. These innovative practices are sure to bring enormous economic, societal as well as environmental practices, as shown in Table 5.6. There is a need to further investigate the feasible innovation that can be practiced in countries considering parameters such as budget requirements, the climatic conditions as well as the impact and the geographic requirement of the region. These innovative techniques will enable a method of better management as well as production.

This study identifies and reviews the use of innovative practices internationally in the road construction sector, through different case studies from different countries. Three main implications for governments, the public and the construction industry can be derived from this study.

First, the use of methods that make the roads self -sustained and energy independent from the non-renewable sources is a very beneficial innovation that benefits both the environment and the people. These methods include innovation such as the solar roads, energy generation in the roads by wind turbines, the use of the energy liberated as a result of friction from the roads to heat nearby buildings, and use of recycled materials for building roads. All of these are successful innovations that are sure to foster a better future in terms of lowering global warming as well as the carbon footprint. Adoption of these innovative practices can enable any road construction industry to tackle the biggest problems that it is currently dealing with: global warming and climate change.

Second, the use of recycled materials can prove cost effective as the bitumen and asphalt that are used as a road building material contribute to the greatest amount of cost that the economy has to bear in road construction. Also, the use of Pre- cast Pre-Stressed Pavement can decrease the time that is required to build roads as well as highways and also enable the safety of the workers. Building or repairing existing roads is time-consuming and also disturbs the road traffic so the use of PCCP can enable building as well as repairing roads while not disturbing the traffic to a great extent.

Third, the use of innovative methods of production, technologies as well as practices, can lead to enormous economic benefits to any country. Some of the benefits are through the adoption of greener methods of road construction whereby the negative environmental impact owing to the building of roads can be minimised. These methods can also ensure the use of modern technology leading to improvement in the current construction process adding automation and computerised control. There can be a reduction in the road accident level by the use of some technologies such as the highways that have signs that glow in dark and indicate weather conditions. These would enable the drivers to see road signs irrespective of the availability of power supply leading to a reduction in causalities. Also recycled asphalt and using wastes from industries are the methods that can lower the total cost of road construction, leading to savings in the national spending. These innovative practices can lead to the construction of roads that are sustainable as well as durable and require less maintenance, furthering savings in the cost of road maintenance, which is a significant cost that this sector has to incur.

References

AASHTO. (2004). *Guide for Mechanistic-Empirical Design of New And Rehabilitation Pavement Structures, NCHRP 1-37A Final Report*. Washington, D.C.: ERES Consultants Division, National Cooperative Highway Research Program, Transportation Research Board, National Research Council.

ASTM. (2011). *Safe and Sustainable Highways with ASTM Standards*. Retrieved from http://www.astm.org.

Australian Bureau of Statistics. (2012). *History of Roads in Australia*. Retrieved from http://www.abs.gov.au/ausstats/abs@.nsf/0/2e904c15091c39a5ca2569de0028b416?OpenDocument.

Australian Bureau of Statistics. (2013). *Summary of IT Use and Innovation in Australian Business, 2011-12*. Canbeerra.

Bain, R. (2001). Moveable barrier technology-the key to the dynamic highway? *Traffic Engineering+ Control, 42*(10), 340-342.

Bakker, R., Hogema, J., Huiskamp, W., & Papp, Z. (2005). *IRVIN - Intelligent road and vehicle test INfrastructure.* Paper presented at the IEEE Conference on Intelligent Transportation Systems, Proceedings, ITSC.

Barrett, P., Sexton, M., & Lee, A. (2008). *Innovation in small construction firms*.

Baxter, P., & Jack, S. (2008). Qualitative case study methodology: Study design and implementation for novice researchers. *The qualitative report, 13*(4), 544-559. Retrieved from http://nsuworks.nova.edu/tqr/vol13/iss4/2

C.I.S. Assessment Committee. (2014). *East West Link: Transport Evidence Statement*. Hawthorn East - VIC O'BRIEN TRAFFIC Retrieved from www.dtpli.vic.gov.au/__data/assets/pdf_file/0018/230067/OBrien-EWS-Body-Chapters-1-6.pdf.

Caerteling, J. S., Di Benedetto, C. A., Dorée, A. G., Halman, J. I. M., & Song, M. (2011). RETRACTED: Technology development projects in road infrastructure: The relevance of government championing behavior. *Technovation, 31*(5), 270-283. doi:http://dx.doi.org/10.1016/j.technovation.2011.02.001

Chong-White, C., Hengst, B., Quail, D., Glenn Geers, D., & Goeldner, G. (2008). *NICTA-RTA partnership for traffic control innovation.* Paper presented at the 15th World

Congress on Intelligent Transport Systems and ITS America Annual Meeting 2008.

City of Sydney. (2015). Roads of recycled toner. Retrieved from http://www.cityofsydney.nsw.gov.au/vision/towards-2030/sustainability/roads-of-recycled-toner

Commonwealth Government of Australia. (2001). *Backing Australia's ability : an innovation action plan for the future*. Canberra.

Costa, C. d. (2010). Solar Road Introduction. *Solar Roal a real Solution.* Retrieved from http://www.solarroadways.com

Costa, C. d. (2011). Solar Roadways Could Solve the US Energy Crisis. *Solar Roadways Completes Prototype, Sends Us Pics.* Retrieved from http://www.gadgetreview.com

Davies, A., Brady, T., Tang, P., Hobday, M., Rush, H., & Gann, D. (2003). *Delivering Integrated Solutions*. Retrieved from http://eprints.brighton.ac.uk/4768/

Drejer, A. (2002). Situations for innovation management: towards a contingency model. *European Journal of Innovation Management, 5*(1), 4-17.

Dwyer, A. (2011). *Road Maintenance: Options for Reform*. Sydney: INFRASTRUCTURE PARTNERSHIPS AUSTRALIA.

Dube, D.-E. (2014). Netherlands test-drives world's first glow-in-the-dark highway. Retrieved from http://globalnews.ca/news/1272844/glow-in-the-dark-highway-of-the-future/

EcoFriend. (2011). Future Perfect – Innovative ideas for renewable energy generation on highways. Retrieved from http://www.ecofriend.com/future-perfect-innovative-ideas-for-renewable-energy-generation-on-highways.html

Federal Highway Administration. (2009). *TechBrief: Precast Prestressed Concrete Pavement for Reconstruction and Rehabilitation of Existing Pavements*. U.S. Department of Federal Highway Administration Retrieved from http://www.fhwa.dot.gov/pavement/concrete/pubs/if09008/index.cfm#s10.

U.S. Department of Transportation: Federal Highway Administration. (2015). *Construction of the California Precast Concrete Pavement Demonstration Project*. (FHWA-IF-06-010). Washington, DC Retrieved from http://www.fhwa.dot.gov/pavement/concrete/pubs/if06010/ch1.cfm.

Gambatese, J. A., & Hallowell, M. (2011a). Enabling and measuring innovation in the construction industry. *Construction Management and Economics, 29*(6), 553-567. doi:10.1080/01446193.2011.570357

Gambatese, J. A., & Hallowell, M. (2011b). Factors that influence the development and diffusion of technical innovations in the construction industry. *Construction Management and Economics, 29*(5), 507-517. doi:10.1080/01446193.2011.570355

Green Energy. (2015). Futuristic Benefits of Solar Roadways. Retrieved from http://cleangreenenergyzone.com/futuristic-benefits-of-solar-roadways/

Hamdani, D. (2000). *Services Indicators: Innovation in the engineering services industry*. Retrieved from http://www5.statcan.gc.ca/olc-cel/olc.action?objId=63-016-X19990034860&objType=47&lang=en&limit=0.

Hartmann, A. (2006). The context of innovation management in construction firms. *Construction Management and Economics, 24*(6), 567-578. doi:10.1080/01446190600790629

Hruska, J. (2014). The Netherlands has laid the world's first solar road – we go eyes-on to investigate. Retrieved from http://www.extremetech.com/extreme/194313-the-netherlands-has-laid-the-worlds-first-solar-road-we-go-eyes-on-to-investigate

ICAX. (2011). cuts through the ice saves lives and prevents accidents reduces risks and road salt pollution and prolongs the life of roads. *Toddington Demonstration for the Highways Agency*. Retrieved from http://www.icax.co.uk

ICAX. (2015). Solar Road Systems cut through the ice, save lives and prevent accidents. Retrieved from http://www.icax.co.uk/toddington.html

Indian Highways. (2010). Need for innovations in road construction. Retrieved from http://irc.org.in/ENU/knowledge/Editorial/September%202010.pdf.

Inhabitat. (2009). Solar Roadways to Prototype First Ever Solar Road Panel *Go Green*. Retrieved from http://inhabitat.com

Innovation Seed. (2012). Recycled asphalt used for the sustainable construction of roads. Retrieved from http://www.innovationseeds.eu/Policy-Library/Core-Articles/Recycled-Asphalt-Used-For-The-Sustainable-Construction-Of-Roads.kl

Jones, S. (2011). Geothermal stations harness heat from passing crowds. Retrieved from https://www.forumforthefuture.org/greenfutures/articles/geothermal-stations-harness-heat-passing-crowds

Kaare, K. K., & Koppel, O. (2012). Improving the road construction supply chain by developing a national level performance measurement system: the case of Estonia. *International Journal of Social and Human Sciences, 6*(2), 225-231.

Katharine, J. T. (2014). Netherlands Is The 1st Country To Open A Solar Road For Public Use. Retrieved from http://www.collective-evolution.com/2014/11/09/netherlands-is-the-first-country-to-open-solar-road-for-public/

Kilby, P., & Johnson, F. (2010). *RTA and NICTA: Innovating on Successful Traffic Management.* Paper presented at the 17th ITS World Congress.

Koudstaal, A., & Jorritsma, S. (2015). PlasticRoad Retrieved from http://en.volkerwessels.com/en/about-us/profile/profile

Lemus, A. B. D. M. I. B. A., Dr. Miguel A. Orta, J.D.M.I.B.A., Prof.Edel. (2015). Leading Innovation Change in Today's Competitive Environment. *Global Journal Of Management and Business Research, 15*(2).

Lighting Matters. (2015). LED road lights improve accident black spots. Retrieved from http://lightingmatters.com.au/wp/led-road-lights-improve-accident-black-spots/

Ling, F. Y. Y. (2003). Managing the implementation of construction innovations. *Construction Management and Economics, 21*(6), 635-649. doi:10.1080/0144619032000123725

Lindsay Corporation. (2015). Moveable Barrier. Retrieved from http://www.lindsay.com/moveable-barrier

Loosemore, M. (2014). Serendipitous innovation: Enablers and barriers in the construction industry. In Proceedings 29th Annual Association of Researchers in Construction Management Conference, ARCOM 2013 (pp. 635-644).

Luna Road. (2011). Luna Road Offers Customizable Solar Road Studs and Solar Cat Eyes. *Luna Road - Light System.* Retrieved from http://powerandenergynews.com

Macdonald, F. (2015). The solar road in the Netherlands is working even better than expected. Retrieved from http://www.sciencealert.com/solar-roads-in-the-netherlands-are-working-even-better-than-expected

Manley, K. (2006). *Identifying the determinants of construction innovation*. Paper presented at the Joint International Conference on Construction Culture, Innovation and Management, Dubai.

Manley, k. (2008). Implementation of innovation by manufacturers subcontracting to construction projects. *Engineering, Construction and Architectural Management, 15*(3), 230-245. doi:10.1108/09699980810867398

Manley, K., & Blayse, A. M. (2004). *Innovation In The Australian Road Construction Industry – Making Better Use Of Resources*. Paper presented at the New Zealand Institute of Highway Technology, Towards Sustainable Land Transport Conference, Wellington, New Zealand. http://eprints.qut.edu.au/7302/

Manley, K., & McFallan, S. (2003). *Innovation adoption behaviour in the construction sector: The case of the Queensland road industry*. Paper presented at the 2nd International Conference on Innovation in Architecture, Loughborough University, United Kingdom.

Merritt, D., Frank McCullough, B., & Burns, N. (2003). Precast prestressed concrete pavement pilot project near Georgetown, Texas. *Transportation Research Record: Journal of the Transportation Research Board*(1823), 11-17.

Merritt, D. K., McCullough, B. F., Burns, N. H., & Rasmussen, R. O. (2004). *Construction of the California Precast Concrete Pavement Demonstration Project*. (FHWA-IF-06-010). Washington, DC Retrieved from http://www.fhwa.dot.gov/pavement/concrete/pubs/if06010/ch1.cfm.

Merritt, D. K., & Tayabji, S. (2009). Precast Prestressed Concrete Pavement for Reconstruction and Rehabilitation of Existing Pavements.   Retrieved from http://www.fhwa.dot.gov/p...e/pubs/if09008/if09008.pdf

Merritt, D. K., & Tyson, S. S. (2006). *Precast Prestressed Concrete Pavement–A Long-life Approach for Rapid Repair and Rehabilitation.* Paper presented at the Proceedings, International Conference on Long-Life Concrete Pavements.

Oad, P. K., Kumar, A., & Kajewski, S. (2016). Innovative Technologies in road sector. 8th International Conference on Maintenance and Rehabilitation of Pavements (MAIREPAV8), Singapore. doi:10.3850/978-981-11-0449-7-136-cd

Petho, L., Beecroft, A., Griffin, J., & Denneman, E. (2014). *High modulus high fatigue resistance asphalt (EME2) technology transfer* (1925037932). Retrieved from https://www.onlinepublications.austroads.com.au/items/AP-T283-14

Petho, L., & Bryant, P. (2015). *High modulus asphalt (EME2) pavement design in Queensland.* Paper presented at the AAPA International Flexible Pavements Conference, 16th, 2015, Gold Coast, Queensland, Australia.

Probst, L., Monfardini, E., Frideres, L., Demetri, D., Schnabel, L., Kauffmann, A., . . . Luxembourg, P. (2013). *Business Innovation Observatory - Environmentally friendly technologies and energy efficiency*. European Union.

Radison, T. (2013). 8 innovations in road surface products and techniques. Retrieved from http://www.on-sitemag.com/features/8-innovations-in-road-surface-products-and-techniques/

Rajasekar, S., Philominathan, P., & Chinnathambi, V. (2013). Research methodology. *arXiv preprint physics/0601009, V3*, 53. Retrieved from http://arxiv.org/abs/physics/0601009v3

Rose, T. M., & Manley, K. (2012). Adoption of innovative products on Australian road infrastructure projects. *Construction Management and Economics, 30*(4), 277-298. Retrieved from http://www.scopus.com/inward/record.url?eid=2-s2.0-84859877998&partnerID=40&md5=b11c5b6a590a417e5b51d3946605bd83

Schroeder, R. L. (1994). The Use of Recycled Materials in Highway Construction. *Public Roads, 57*(2), 8. Retrieved from https://www.fhwa.dot.gov/publications/publicroads/94fall/p94au32.cfm

Sexton, M., & Barrett, P. (2003). Appropriate innovation in small construction firms. *Construction Management and Economics, 21*(6), 623-633. doi:10.1080/0144619032000134156

Slaughter, E. S. (1998). Models of construction innovation. *Journal of Construction Engineering and Management, 124*(3), 226-231.

Solar Roadways. (2016). Solar roads. Retrieved from http://www.solarroadways.com/

Stantchev, D., & Whiteing, T. (2010). Environmental Aspects of Sustainability. Retrieved from http://www.transport-research.info

Ström, E., Hartenstein, H., Santi, P., & Wiesbeck, W. (2010). Vehicular Communications: Ubiquitous Networks for Sustainable Mobility [Point of View]. *Proceedings of the Ieee, 7*(98), 1111-1112.

Suprun, E. V., & Stewart, R. A. (2015). Construction innovation diffusion in the Russian Federation: Barriers, Drivers and Coping Strategies. *Construction Innovation, 15*(3), 278-312. doi:10.1108/CI-07-2014-0038

Tan, M. (2015). Asphalt mix made with recycled printer toner paves way for eco-friendly roads. Retrieved from http://www.theguardian.com/australia-news/2015/may/20/asphalt-mix-made-with-recycled-printer-toner-paves-way-for-eco-friendly-roads

Tayabji, S. D., Barenberg, E. J., Gramling, W., & Teng, P. (2001). *Prestressed Concrete Pavement Technology Update.* Paper presented at the Seventh International Conference on Concrete Pavements. The Use of Concrete in Developing Long-Lasting Pavement Solutions for the 21st Century., Orlando, Florida.

Tayabji, S., & Hall, K. (2008). TechBrief: Precast Concrete Panels for Repair and Rehabilitation of Jointed Concrete Pavement. *CPTP TechBrief, U.S. Department of Transportation, Fedral Highway Administration*, 6. Retrieved from http://www.fhwa.dot.gov/pavement/pub_details.cfm?id=628

Tayabji, S., Ye, D., & Buch, N. (2013). Precast concrete pavements: Technology overview and technical considerations. *PCI journal, 58*(1).

United States Environmental Protection Agency. (2012). *Using Recycled Industrial Materials in Roadways*. Retrieved from New York, United States Environmental Protection Agency:

University of Washington. (2011). "Green Roads." More Sustainable roads for a better transportation future Retrieved from http://www.epa.gov

Whiteing, T., & Stantchev, D. (2008). *Environmental Aspects of Sustainable Mobility: Thematic Research Summary*. Retrieved from http://trid.trb.org/view/2008/M/874548.

World Health Organization. (2009). *Global status report on road safety: Time for action*. Switzerland Retrieved from www.who.int/violence_injury_prevention/road_safety_status/2009.

Yahya, M. A. (2015). AWARENESS IN INNOVATIVE HIGHWAY CONSTRUCTION IN MALAYSIA. *Academia*. Retrieved from https://www.academia.edu/585287/AWARENESS_IN_INNOVATIVE_HIGHWAY_CONSTRUCTION_IN_MALAYSIA

Yin, R. K. (2003). *Case study research: Design and methods* (3rd ed.): Sage publications.

Appendix A

This section contains further information on each selected case study.

Technical Specifications

Technology and Operation	
Solar panel type	825mA mono-crystalline solar panel
Illumination technology	216 x Φ5 Ultra-bright LEDs
Energy storage	9V AGM Battery
Charging time	4 Hours (sunny) to 8 hours (cloudy or rainy)
Temperature range	-40F to +176F / -40C to +80C
On/Off level	24 hours operation
Operation modes	Optional activation/deactivation by sensors, push-button, computer, wireless receiver and the like
Warranty	1 year
Illumination Properties	
Available flash patterns	Slow: 25±2/min Fast: 50±5/min
Available LED colors	White, Blue, Red, Green, Amber
Light visibility distance	Up to 3,300 feet / 1000m (varies according to weather conditions)
Material and Design	
Body	Aluminum and stainless steel
Illumination face diameter	12" / 30.48cm

Appendix A. 1: Technical Specification of Solar Road Lights (Sola Sign, 2015)

Technical Specifications:

Solar cell type	:	mono-crystalline
Voltage	:	3v
Current	:	120mA
Capacitor type	:	super capacitor
Voltage	:	2.3V
Capacity	:	120F
Circle lifespan	:	100,000 circles
Working temperature	:	-40 to +80Aâ€šÂ°C
LED frequency	:	(1Hz , Â± 20%)
Size	:	5mm
Colors	:	white, yellow, red, blue, green
Luminous intensity	:	2,000mcd
Control circuits	:	IC
Compression resistance	:	over 10 tons
Starting intensity	:	500 lux
Lifespan	:	5 years
Waterproof grade	:	IP68
View distance	:	over 500m

Appendix A. 2: Technical Specifications of the Solar Roads Studs (7M, 2015)

Country	*Remarks*	*SMA-DAC*	*PA-DAC*	*EACC-DAC*
Austria	**Light vehicles / 50 km/h**		**-1**	**0**
Austria	**SPBI**	**-3.4 / -1.4**	**-3.3 / -1.3**	**-2.0 / 0.0**
Austria	**CPXI (LMA)**	-3.7 / **+0.3**	**-1.5 / -0.3**	-2.8 / **-1.0**
France	**0/10 mm / Light veh. / 90 km/h**		**-3.9**	
France	**0/10 mm / Light veh. / 50 km/h**		**-3.5**	
Germany	**30-50 km/h**	**0**		
Germany	**0/11 mm / > 60 km/h**	**0.0**	**-2.0**	
Hungary	**0/12 mm**	+2.9		
Italy			**-1.4**	
Japan	**0/13 mm / 50 km/h**		**-2.7**	
Japan	**0/13 mm / 90 km/h**		**-3.6**	
Netherlands	**Light vehicles**		**-2.61**	**-0.07 /** +1.42
Slovenia	**1995**	**-2**	**-3**	
Slovenia	**2003**	-2.1	-6.9	
Spain	**< 60 km/h**		**-1**	
Spain	**> 80 km/h**		**-3**	
Switzerland		**0**	**-4**	
USA	**Light vehicles**		**-1.55**	
Nordic countries	**Max. 16 mm / Light vehicles**	**0 / +1**	-1 / 0	

Appendix A. 3: Correction terms for comparable surfacing for noise reduction

Country	**Definition of noise reducing pavement**
Denmark	≥ 3 dB reduction (reference ~8 years old DAC 11)
Germany	≥ 2 dB SMA (reference non-corrugated mastic asphalt)
The Netherlands	Porous Asphalt (by definition)
Norway	No definition (reference probably DAC 16 / SMA 16)
Sweden	2-3 dB reduction (reference DAC 16 / SMA 16)
Switzerland	4 defined mixes in specification (reference general level)
United Kingdom	Any surface ≥ 2.5 dB reduction (reference Hot Rolled Asphalt)

Appendix A. 4: Specification for noise reducing pavements (Bendtsen, et al., 2008)

Appendix A. 5: Product innovation obstacles (Rose, T. M., & Manley, K., 2014)

Rank	Innovation obstacle	Mean	Contextual source	Obstacle interpretation
1	Restrictive tender assessment criteria (e.g. price-only)	5.70	Procurement systems	Underemphasis on value selection, including non-price criteria in contractor selection process within the selected procurement systems
2	Disagreement between industry participants over who carries the risk of new product failure	5.44	Industry relationships	Lack of acceptance and transparency in how product risk is allocated across the innovation network impacting on the decision to adopt
3	Adversarial contract relations that inhibit adoption of new products on projects	5.43	Industry relationships	Weak project relationships impacting on ability for effective innovation knowledge sharing
4	Contractor time pressure inhibiting ability to consider new product ideas	5.40	Organizational resources	Lack of contractor resources to consider new product ideas from suppliers in light of time constraints
5	Time pressure within the Australian road agency in your state inhibiting ability to consider new product ideas	5.39	Organizational resources	Inadequate client road agency resources to effectively consider new product ideas from contractors and consultants in light of time constraints
6	New product ideas that save project cost but impose higher costs over the life of the road or bridge asset	5.38	Procurement systems	Overemphasis within the procurement approach on short-term financial goals to the detriment of long-term outcomes
7	Difficulty in getting the road agency in your state to trial new products	5.37	Organizational resources	Inadequate client road agency resources to effectively trial new product ideas from adoption from contractors, consultants and suppliers
8	Incentives that favour new products that save project cost, over new products with other types of benefits	5.36	Procurement systems	Imbalanced contractual incentives within the procurement approach focusing on project cost performance to the potential detriment of other performance objectives
9	Insufficient involvement of contractors early in the design phases of a project	5.36	Procurement systems	Failure to capture the effective contribution of the contractor earlier under the project procurement approach, lessening the opportunity to propose innovative solutions
10	Heavy reliance on tightly prescribed/restrictive specifications by the Australian road agency in your state	5.33	Regulatory conditions	Tight regulatory conditions that limit the opportunity for project organizations to propose alternative innovative solutions resulting in less flexibility to experiment with innovative ideas
11	Difficulty in getting suppliers of new products to conduct sufficient testing prior to presentation to their clients	5.28	Organizational resources	Inadequate supplier resources to effectively conduct sufficient testing prior to submission, resulting in risk-averse attitude towards the innovative products
12	Disagreement over the appropriate period for new product warranties	5.25	Industry relationships	Lack of acceptance and transparency over the appropriate warranty length for innovative products across industry
13	Difficulty in getting suppliers of new products to accept extended warranties to cover increased risks associated with new products	5.24	Organizational resources	Inadequate supplier resources to effectively warrant their innovation over the long term to meet client requirements
14	Infrequent use of performance-based specifications by the Australian road agency in your state	5.16	Regulatory conditions	Client risk averseness towards alternative technical regulatory approaches, such as performance-based specifications, limiting the opportunity for project organizations to propose alternative innovative solutions

(Continued)

Appendix A. 5: continued

Rank	Innovation obstacle	Mean	Contextual source	Obstacle interpretation
15	Lack of clear procedures with the Australian road agency in your state for assessment of new product ideas	5.15	Regulatory conditions	Lack of agreed innovation assessment processes within the regulatory environment across state government jurisdictions
16	Insufficient involvement of suppliers early in the design phases of a project	5.14	Procurement systems	Failure to capture the effective contribution of product suppliers earlier under the project procurement approach, lessening the opportunity for innovation to be adopted
17	Disagreement between industry participants over who is responsible for testing new products	5.11	Industry relationships	Lack of acceptance and transparency in the allocation of responsibility for testing innovative products for use impacting on the decision to adopt
18	Duplication of trialling effort to meet the needs of different Australian road agencies	5.00	Regulatory conditions	Lack of agreed and compatible innovation trialling processes within the regulatory environment across state government jurisdictions
19	Lack of expertise on the part of new product suppliers (manufacturers, distributors, contractors or consultants) to accurately assess the performance capability of new products	4.97	Organizational resources	Inadequate supplier organizational competencies to accurately assess the performance capability of innovations
20	Lack of expertise within the road agency in your state to accurately assess the performance capability of new products	4.94	Organizational resources	Inadequate organizational competencies within the client road agencies to accurately assess the performance capability of innovations
21	Lack of expertise within the road agency in your state to accurately assess the performance intention of prescriptive specifications	4.86	Organizational resources	Inadequate organizational competencies within the client road agencies to accurately assess the performance intention of innovations, resulting in the difficulty to specify performance requirements
22	Inequities in the treatment of different types of new product suppliers (e.g. lone inventors, large manufacturers, contractors) by the Australian road agency in your state	4.69	Organizational resources	Inadequate organizational resources within the client road agencies to effectively capture the potential contribution of lone inventors in comparison to larger organizations

Appendix A. 6: Innovation diffusion Barriers (Suprun, E. V., & Stewart, R. A., 2015)

Barrier category	Barrier	Reference	Definition/comments
Economic conditions	High construction cost	Hydes and Creech, 2000; HSE, 2013; Miozzo and Dewick, 2004; Stewart and Mohamed, 2000, 2002	The nature of additional investments may come from price increases on new materials, use of technologies, consultants' fees and high expenses for the professional development of the contractors, managers and design team.
	Substantial economic risk	Denisov and Kamenetskiy, 2003; Loosemore, 2014; Miozzo and Dewick, 2004; Slaughter, 1998; Taipale, 2010	The reasons for the risk are lack of existing information, adoption of unfamiliar techniques and ideas, lack of government and manufacturer support, lack of experience and uncertainty of the success of the construction process.
	Expectation of short-term profit	Budworth, 1996; Grigoryev, 2011	A large number of investors and owners of construction companies focus only on how much profit they will obtain; as a result, expenditure on innovation is reducing in favour of the use of traditional, well-recognised methods.
Regulations,	Restrictions imposed by regulations Tendering and	Blayse and Manley, 2004; Bowley, 1966; Ling, 2003	These regulations include building codes and certificate schemes. The building and construction industry is different from many other industries, where firms compete via marketing campaigns and new products. The use of tenders and project procurement might be a
public policy and supporting mechanisms	procurement	de Valence, 2011	Serious obstacle to innovation implementation in the construction industry because the traditional tendering process for building works usually does not encourage widespread design innovation.
	Administrative barriers	National Association of Home Builders (NAHB), 2004	Administrative barriers include the variety of building codes and standards as well as the regional features of both technical and legal aspects; low levels of government support for industry development; the often hostile attitude of designers and builders to the tender process; and government contracts with inflexible fixed budgets.
Research and development collaboration		NAHB, 2004	The research component includes fragile contracts between university research centres and the construction industry, limited funding for innovation research and the lack of established schemes for commercialising research.
Availability of information, methods and tools		Grigoryev, 2011; Veshosky, 1998; Stewart *et al.*, 2004	The design team and project managers need to have access to the best available information on technologies and tools in order to introduce the innovation in the stages of design and construction. A lack of information and modern technologies, such as automatic calculation procedures, is a serious obstacle to effective cooperation between all the actors involved in the construction process. Further, access to up- to-date tools is required for optimal operational process during a building's life cycle.
Cooperation between all construction process	Fragmentation of the industry	Davidson, 2013; HSE, 2013; Nam and Tatum, 1992; Pries and Janzen, 1995; Stewart and	The innovation process requires close interaction between professionals, suppliers and users. However, in reality, designers, contractors and consultants are isolated from each other. By setting developing goals, public building processes may initiate private design and construction companies into modern methodologies.

Continued

Appendix A. 6: continued

stakeholders	Disinterest of designers and architects	Mohamed, 2000, 2002	the building materials industry by including advanced materials and innovative technologies in their projects. However, designers tend not to take risks without
Client and developer understandin g	Demand and willingness of clients and developer	Gumba, 2009; Ivory, 2005	As clients, government and local authorities significantly affect the use of new materials, technologies and methods, in contrast to the private sector. However, a private client may also suppress innovation, in the case of public and residential construction, because the client has to bear all the risk of the innovation while the users reap the
	Fear of innovation implementation	Ivory, 2005; Nam and Tatum, 1992	The most common fear is a risk of defects in the future; obviously, clients want to avoid any risk associated with innovations. Technologies that appear infallible initially may show defects during the long-term operation of buildings, roads, bridges and other structures.

Appendix A. 7: Drivers for Innovation (Suprun, E. V., & Stewart, R. A., 2015)

Driver category	Driver	Reference	Definition/comments
External pressure and support	Market environment	Mitropoulos and Tatum, 2000; Nam and Tatum, 1992; Sayfullina, 2010; Stewart, 2007	It was found that innovations were implemented because of market demand. The capturing of competitive advantage is one of the factors forcing innovation adoption.
	Regulations	Gann *et al*., 1998; HSE, 2013; Mitropoulos and Tatum, 2000	Regulations can affect innovation implementation in two ways: by forcing companies to innovate through detailed specifications and strict standards as well as by urging progressive innovators in a certain direction through public support, awards, subsidies and grants.
Knowledge exchange	Information gathering	Kangari and Miyatake, 1997; Veshosky, 1998	Many studies recognise information and knowledge sharing as an effective motivating factor for innovation implementation. Consequently, there is a need for innovation both within and between companies.
	Cooperation between participants of the construction process	Barlow, 2000; Gumba, 2009; Mitropoulos and Tatum, 2000; Nam and Tatum, 1992; Tatum, 1989	Cooperation is an effective enabler of the innovation process because it allows all involved participants to share the project risks and benefits. For innovation stimulation, construction firms depend on suppliers of innovative materials and tools as well as clients who involve themselves in the construction project.
	Personnel participation	Barlow, 2000; Bowen and Thomas, 2004; Dulaimi *et al*., 2002; Love *et al*., 2002	Many authors highlight the importance of personnel participation in all firm-level innovation processes, as well as the need to hire new specialists and graduates. The innovation process requires experts who are capable of and willing to implement effective innovations. Firms should create conditions that encourage personnel to experiment with new ideas.
	Coordination with universities and scientific research institutes	D'Este and Patel, 2007; Nam and Tatum, 1992	Research and development (R&D) is an important factor, because many new materials and technologies are introduced as the result of long-term research and new product development.
Technological and technical capability		Caloghirou *et al*., 2004; Gumba, 2009; Miozzo and Dewick, 2004; Nam and Tatum, 1992; Stewart *et al*., 2004; Tatum, 1989	This category represents the technical and technological capabilities of a firm that enable the industry to implement innovative products, solutions, technologies and processes as well as quickly adapt to new opportunities. The introduction of new materials, technologies and processes is an important instrument and the main technical driver of innovation. Continuous integrated R&D efforts are required for effective implementation of technology-using strategies.

Appendix A. 8: Measures for overcoming barriers to innovation diffusion (Suprun, E. V., & Stewart, R. A., 2015)

Barrier	Strategy
High construction costs (funding deficit) Substantial economic risk Expectation of short-term profit Limited funding for innovation research Low level of government support for industry development	**Economic incentives support:** • federal targeted programmes • funding through the scientific and technological departments • direct financial investments • foundation of clusters, including special economic zones • investment preferences associated with the purchase of technological equipment • fiscal incentives Stimulation of demand for innovative local manufacturing components and products
Restrictions imposed by regulations The variety of building codes and standards Regional features in both the technical and legal aspects Fragile contracts between university research centres and the construction industry Lack of established promotion schemes for innovations from research laboratories to testing in an operational environment Hostile attitude of designers and builders to contracts with fixed prices	Improvement of legislation: • harmonisation of Russian building codes with Eurocodes • development of new building standards and improvement of technical regulations regarding the use of advanced technologies and materials • legislative support for scientific research institutes • introduction of responsibility for construction quality • improvement of the certification process State programme for world-class sporting and political events
Tendering and procurement	Non-traditional forms of procurement
Non-effective cooperation between all members of the construction process	Development of teamwork and competence of designers Professional education
Fear of innovation implementation Lack of demand and willingness of clients and developers Lack of all necessary information and modern technologies	Development of availability to work with appropriate information and tools Engagement with public pilot projects

Appendix A. 9: Technical Specification for EME2 (Petho et al., 2014)

Property	Test method	Unit	Limit	Binder 15/25 pen	Binder 10/20 pen
				Value	Value
Penetration at 25 °C	AS 2341.12	pu(1)	Minimum Maximum	15 25	10 20
Softening point	AS 2341.18	°C	Minimum Maximum	56.5 72.5	59.5 79.5
Viscosity at 60 °C(3)	AS 2341.2	Pa.s	Minimum	900	1050
Loss on heating	AGPT-T103	%	Maximum	0.5	N/A
Retained penetration(2)	AS/NZS 2341.10, AS 2341.12	%	Minimum	55	N/A
Increase in softening point after RTFO treatment	AS/NZS 2341.10, AS 2341.18	°C	Maximum	8	10
Viscosity at 135 °C	AS 2341.2, AS 2341.3, AS 2341.4 or AGPT-T111	Pa.s	Minimum	0.6	0.7
Matter insoluble in toluene	AS 2341.8	% mass	Maximum	1.0	N/A
Penetration index	N/A	N/A	N/A	Report	Report
Viscosity at 60 °C after RTFO(3)	AS/NZS 2341.10 AS 2341.2	Pa.s	N/A	Report	Report
Per cent increase in viscosity at 60 °C after RTFO test	AS/NZ 2341.10	%	N/A	Report	Report

1 One pu equals 0.1 mm.
2 Per cent change in penetration shall be calculated using the equation: (Penetration at 25 °C after RTFO x 100) / (Penetration at 25 °C before RTFO).
3 Test shall be performed using an Asphalt Institute viscosity tube.

Appendix A. 10: New and Innovative Treatments (Suprun, E. V., & Stewart, R. A., 2015)