The effects of improved road infrastructure on social factors in developing countries

A case study of Namibia

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Preface

In front of you lies the result of six months of hard work: my master thesis. The study aims to provide a method to investigate the effects of improved road infrastructure on social factors in developing countries and to apply this method to the country of Namibia. Conducting research on developing research with its huge lack of data was the most challenging and at the same time the most exciting part of this research. Doing a case study on a country which I have visited twice the last year and which stole my heart made it even more interesting and fun.

I would like to express my gratitude for the supervision I received during the project. First of all, Erik, thank you for convincing me to change my thesis subject and to join the ride on this challenging project and for all your help. Secondly, Maaike, I would like to thank you for reading my research so thoroughly and having great recommendations for major improvements. Lastly, Caspar, thank you for your inspiring thoughts and comments on my research and for always providing a personal and positive space during our meetings. I hope that all of you, despite or maybe because of the somewhat odd research I did, enjoyed the experience as much as I did.

Lastly, I want to thank my family and friends for their support during these past couple of months. My parents and sister for being there when most needed and reading through my work. To my mom; thank you for always convincing me that everything will turn out right when everything seemed to go wrong and putting up with me whenever I needed you. My friends and roommates, thank you for all the distraction and support I needed. And Michael, thank you for being patient with me and my questions about Namibia and for being here.

Charlotte Lucas
Delft, June 2019

Executive Summary

I. Research Context

As of today, 783 million people live below the international poverty line of US$1.90 a day and 815 million people are undernourished (United Nations, 2018e). These numbers on poverty and hunger are only two of the seventeen Sustainable Development Goals (SDGs) as deployed by the United Nations (UN) in 2015. The SDGs aim to end poverty, protect the planet and ensure that all people enjoy peace and prosperity (United Nations, 2018d). One of these SDGs focuses on industries, innovation and infrastructure, where infrastructure provides the basic physical facilities essential to business and society (United Nations, 2016).

Different researches acknowledge the effect of physical infrastructure on the economic growth and the reduction of poverty (Esfahani & Ramírez, 2003; Jimenez, 1995; Yoshino & Nakahigashi, 2000). Due to limited expenditure, big investments such as infrastructure investments are fundamental and crucial for developing countries. More insight in the exact effects that investing in transport infrastructure has on socio-economic factors within a country is needed. There is a limited amount of research on the effects of transport infrastructure in developing countries on these factors. Also, most researches have investigated one single effect of transport infrastructures or imposed challenges of each separate factor as a static relationship. Since most governments of developing countries only have a limited expenditure and have to make fundamental choices with regards to investments in certain sectors, it is very important to be able to get more insights in these effects. Therefore, the aim of this research is **to develop a method for investigating the effects of road infrastructure on road safety, emissions, economic growth, health, education, tourism and employment and secondly, it applies the research plan to Namibia**. Namibia is a developing country in Southern Africa and is part of the Southern African Development Community (SADC). National plans emphasise on the ambition of becoming the logistics hub of the SADC by 2022. To achieve this ambition and to grow as a country in general, large amounts of money are invested in the road infrastructure in Namibia.

II. Research Approach

The research is carried out based on a Systems Engineering (SE) methodology, which is a discipline or a way of thinking that manages problem solving processes in the context of socio-technical questions and which looks at a problem in its entirety and aims to enable the realisation of successful systems (INCOSE, 2007; Züst & Troxler, 2006). Using Systems Engineering as a methodology for this research means that the study is divided into three phases: definition, development and deployment. The definition phase includes (i) a literature study in which the relations between road infrastructure and economic growth, road safety, emissions, education, health, employment and tourism are identified; (ii) a country analysis of the country Namibia in terms of socio-demographic status and transport infrastructure situation; (iii) a spatial data analysis in which the relations between variables of which data is available are tested and (iv) explanations behind the data that is used. Phase two describes the model development with the help of System Dynamics (SD). The model is developed based on a data- and theory-rich modelling approach, which implies that the used data is embedded in a proper theoretical framework in which the data can provide useful insights and theory can explain relations and substantiate assumptions. Phase three identifies two possible future scenarios and uses the model to analyse the effects on the factors of these scenarios.

III. Literature study

The literature study examined (i) how transport infrastructure enhances sustainable development, (ii) the most important (underlying) relations between road infrastructure and economic growth and (iii) which method is most suitable for this research. The eighth SDG says to "promote sustained, inclusive and sustainable economic growth, full and productive employment and decent work for all" (United Nations, 2018c). According to Fuente (2010); Melo et al. (2013); Pradhan & Bagchi (2013) transport infrastructure positively influences economic growth. The magnitude of the effect is higher in developing countries according to many researchers (Candelon et al., 2013; Fuente, 2010; Lakhera, 2016). There is usually a lot to gain and influence in developing countries with regards to transport, transport policies and transport investments. Hence, this research focuses on the transport infrastructure in developing countries. Transport infrastructure affects more factors than economic growth. A theoretical framework compassing all relations found in this literature study is shown in figure 1. A bidirectional relation between road infrastructure and economic growth

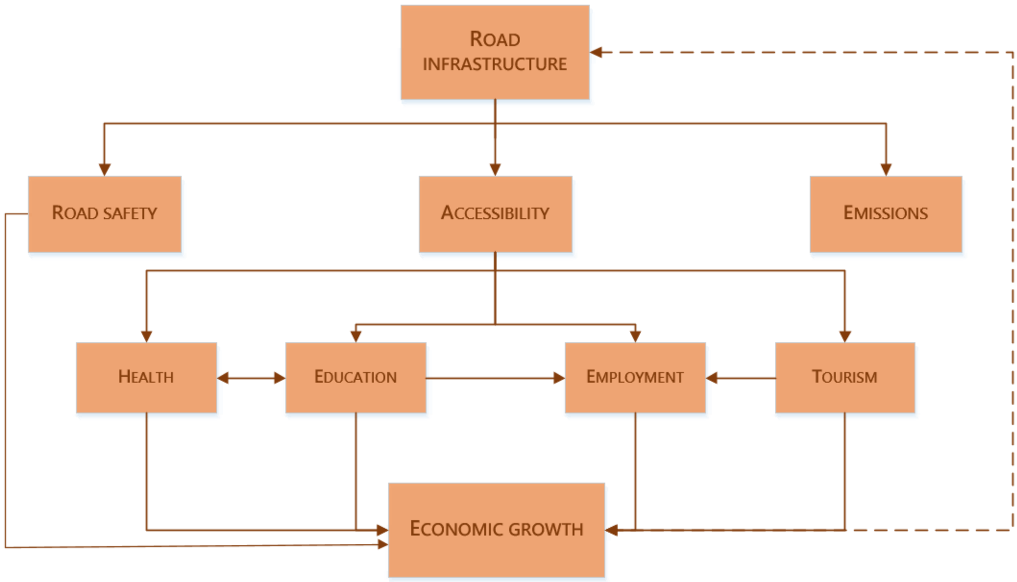

Figure 1: Theoretical framework based on literature study

is identified (Lakshmanan, 2011; Pradhan & Bagchi, 2013). However, both relations are highly context and decision-making dependent and are therefore seen as *uncertain*, which means that the relation is not able to be relied on, not known or not definite. The uncertain relations are indicated by dashed lines. Besides, road infrastructure influences road safety. The magnitude and the polarity of the relation are mostly dependent on the type and material of the roads (Figueroa et al., 2013). Road safety is a major issue with regards to road infrastructure, mainly in developing countries. Furthermore, road infrastructure investment (currently) inevitably leads to more emissions. Overall, the materials seem to cause the largest amount of emissions (Hanson & Noland, 2015). The general accessibility increases through improved road infrastructure. General accessibility enhances tourism Khadaroo & Seetanah (2008), health (Airey, 1991; Donnell O', 2007; Fedderke & Bogetić, 2009; Sperling, 2002), education (Brenneman & Kerf, 2002; Porter, 2010; Siddhu, 2011; Vasconcellos, 1997) and employment (Akinbobola & Saibu, 2004; Sperling, 2002). These relations have reciprocal relations as well. Improvement of each of these factors has a significant positive effect on a country's economic growth according to different researchers.

Lastly, the literature study examined the most suitable method to capture spatial dynamics as come forward in this study. This appears to be System Dynamics (SD) which is "a method to describe, model, simulate and analyze dynamically complex issues and/or systems in terms of the processes, information, organizational boundaries and strategies" (Pruyt, 2013). The fundamental principle of SD is that structure determines behaviour (Brailsford, 2008). By allowing for estimating effects of a policy measure on a system - in particular a country - and by giving insight in (long term) results and effects of a policy measure such as road infrastructure investment on a system or country, this approach is very suitable for the spatial transportation dynamics as in this study.

IV. Country analysis - Namibia

In order to get insights in and an overview of the country Namibia, the socio-demographic status and the transport infrastructure situation are investigated. To do so, both data and sources such as government websites and annual reports of relevant organisations are used. Namibia is the second lowest densely populated country in the world with 2533794 inhabitants (United Nations Department of Economic and Social Affairs, 2017). Large parts of the country are uninhabitable due to land characteristics such as desert and mountains and large privately owned surfaces. Health, education and employment status are not stable and not in an alarming state but can all use large improvements. The economy is growing each year but is highly dependent on droughts, since there is a continuous scarcity of water in Namibia whereas the demand keeps increasing. The electricity supply is sufficient in urban areas but lacks in most rural areas. The same goes for ICT, which the government attempts to improve.

As for the transport infrastructure; Namibia has a relatively good and extended transport infrastructure. All four modalities - air transport, rail transport, sea transport and road transport - are present and used daily but the road infrastructure is by far the most advanced and most used. There are some attempts to improve the current transport situation in terms of safety, social and economic problems and sustainability. However, no reports on the actual outcomes of these attempts have been published yet and therefore it is hard to gauge if the projects improved the addressed issues. Besides, given past developments and future ambitions such as becoming the logistics hub of Southern Africa by 2022, the reality is that the road sector will keep on investing in roads in the near future. Therefore, this thesis only focuses on road infrastructure in Namibia.

V. Data analysis

A multiple regression analysis is conducted to determine the relation between road density and quality and factors on which data is available on constituency level. These factors are education, health and employment. Road density and quality are not the only influencing variables for those factors, hence, if data was available, other predicting variables are also taken into account. This is indicated for each factor below.

For primary school, the number of schools per surface and the material of the walls of a household's house are used as predictive variables. The materials of the walls is a derivative of the welfare of the household. It is found that the road density influences the primary school enrolment together with the schools per surface and the materials of the walls. Not all three independent variables came out significant; road density remains insignificant. To avoid high insignificance and some reciprocal correlation, the schools per surface are taken out. It is logical that material of the walls predicts the education enrolment a lot more, since that is a derivative of income level. However, together with findings in literature, it can be concluded that the higher the road density, the higher the primary school enrolment. Hence, education enrolment can be improved through a higher road density.

As for the relation between road infrastructure and health; the under-five mortality rate (U5MR) is influenced by the access to safe water, apart from accessibility. The water access explains the U5MR for a large part, which is supported by literature. Water access mostly affects the U5MR through diseases such as diarrhoea. Hence, it is logical that this coefficient is large and significant. The road quality expressed in earth road ratio also explains the U5MR, from which it can be concluded that the quality of road infrastructure matters for (the accessibility of) health (care). The road density is not found to be significant in the multiple regression analysis, but with findings from literature and it correlating with U5MR by itself, road density is still used as a predictor for the U5MR, but just with a very small impact. Hence, a better road infrastructure slightly decreases the U5MR.

There are no other predicting variables for employment used than road density and quality. The quality of roads is the biggest predictor of unemployment rate. Road density comes out insignificant, but with confirmation from the literature study and the fact that singular regression between road density and unemployment does come out significant, road density can still be used as independent variable for the unemployment.

Lastly, of the reciprocal relations as shown in the framework, only the relation between health and education is confirmed by the data. The positive relation means that a better health usually goes hand in hand with a better education attendance rate and the other way around.

VI. Explanations behind the data

Since the data shows largely discrepant performances of constituencies with similar road densities, chapter 5 looks into reasons or explanations for this discrepancy. There is not one obvious reason for this, although probably the main reason for a lot of constituencies having a low road density is the large uninhabited areas in the constituency. Another reason is that some of the (mostly northern) constituencies do not have many roads themselves but are close to other big towns so they still have quite good access to facilities. A third reason can be the shapefile containing mistakes. All in all, there is no easy way of accounting for discrepancy in performance of constituencies with similar road densities. These different explanations indicate that road density is not a comprehensive and strong indicator of road infrastructure. Unless used tactfully and logical, road density is not a meaningful way of measuring or assessing road network. An increase in road density could - in theory - imply constructing new roads anywhere within a constituency and performance on factors would go up (according to the data analysis). Therefore, one should bear in mind that, when using road density as a metric, attention has to be paid on where to construct roads and how much. Hence, if road density is used as a metric to assess road infrastructure, it should be used carefully and well-thought-out. To do so, future scenarios are identified in the next section that take this into account.

VII. Model development

To test the effects of improved road infrastructure in future scenarios, a System Dynamics (SD) model is built. Figure 2 shows an overview of the Causal Loop Diagram (CLD) of this study, in which the relations between all variables are indicated. An important aspect of SD is including feedback structures, which are represented by

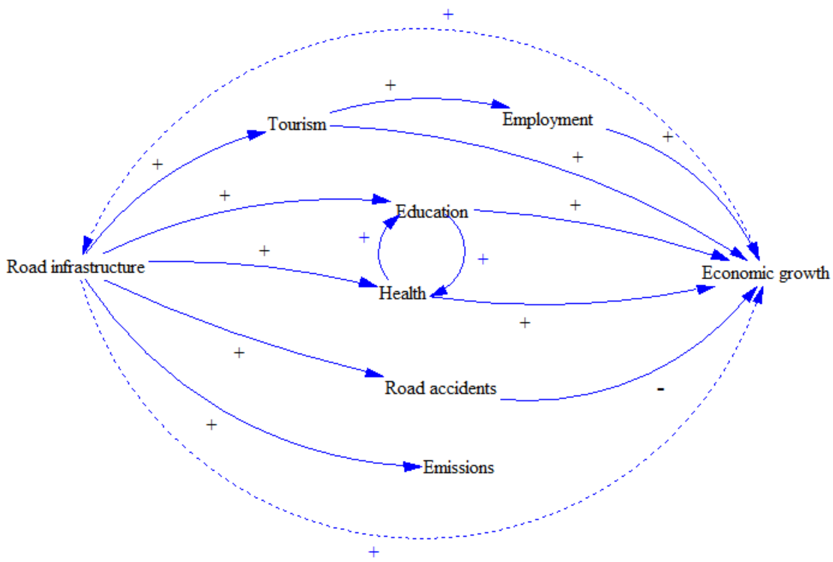

Figure 2: Causal Loop Diagram

feedback loops consisting of causal links from one variable connecting back to that same variable, after connecting to other variables (Sterman, 2000). Feedback loops often play a big role in the overall behaviour of the model which makes it important to identify them. The feedback loop in the framework of this study (figure 1) is represented by the bidirectional relation between road infrastructure and economic growth. The dashed line in the framework indicates the uncertainty of the relationship. Figure 2 shows the causal loop diagram of this study. A common way of dealing with uncertainties in SD is to explore the uncertainties, attempt to reduce the uncertainties as much as possible and to accept the irreducible uncertainties (Pruyt, 2013). Two models are developed; one without uncertainties and one with uncertainties. Both models include the following model components: road infrastructure, economic growth, education, health, employment, tourism, road safety and emissions. These variables are connected as shown in figure 2. The extended model includes the uncertain relations indicated as dashed lines between road infrastructure and economic growth by using sensitivity analysis varying the magnitude of the relationship between 0 and the maximum value. A benefit of using SD for this study is that it allows for incorporating multiple and different geo-spatial scales, for instance national, regional and local within one model. This is called multi-scale modelling. It ensures that the model will remain small and uncomplicated, while processing large amounts of data. Besides, it leads to the possibility of decision-making on different levels, for instance education, health and employment wise data is available on constituency level and hence decisions can be made on that level. For tourism it makes sense to make regional and country policy and decisions. This can all be done based on the same model. The models are verified with the mass balance test, which tests if the model output remains zero if road construction and upgrading is set to zero.

VIII. Future scenarios

Two possible future scenarios with regards to road infrastructure in Namibia are identified: (i) the ambition of becoming the logistics hub of Southern Africa by 2022 and (ii) tourism enhancing. The model without the uncertainties is used to obtain the results as discussed below. The outcomes of the uncertainty model are briefly discussed after. The model is run from 2011 until 2022. The results as shown in the tables below have percentages included indicating the change of each factor between 2011 and 2022. 0 means that there has been no change over time.

RESULTS SCENARIO 1 - LOGISTICS HUB 2022

Table 1 shows the improvements on road density, child mortality, unemployment and injuries due to the improvement of roads in the logistics hub scenario. The figures show the change from 2011 to 2022 of tourism and GDP on country level. The GDP is influenced by health, education, employment, tourism and road safety and therefore shows a different shape for instance the tourism graph by itself.

Table 1: Output KPIs - scenario 1

Constituency	Road density	Child mortality	Unemployment	Injuries
!Nami=Nus	+ 2,2%	- 5,1%	- 6,1%	0
Onyaanya	+ 15,7%	- 34,0%	- 3,5%	+ 2,7%
Musese	+ 9,1%	- 6,0%	- 8,2%	0
Linyanti	+ 4,4%	- 1,6%	- 7,1%	0
Mariental Urban	+ 3,1%	- 4,9%	- 8,1%	+ 3,8%
Sibinda	+ 7,1%	- 6,9%	- 6,5%	0

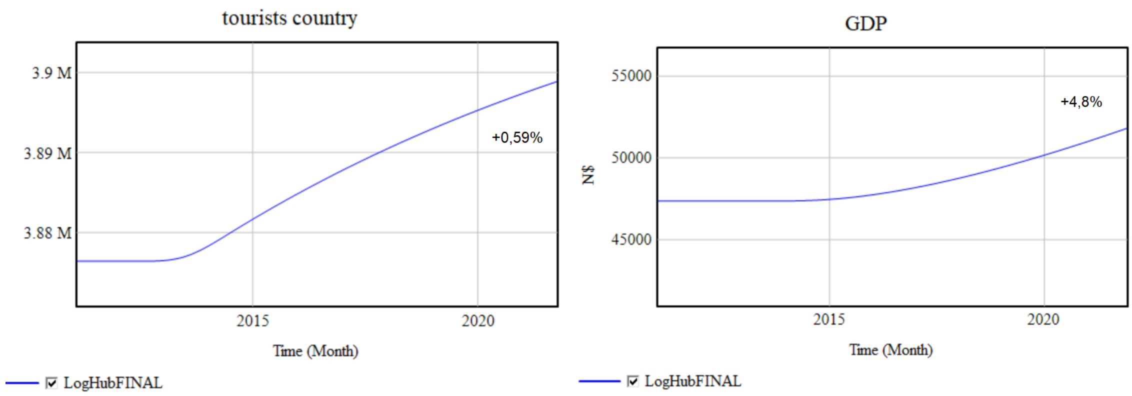

Figure 3: Increase of tourists and GDP in scenario 1

RESULTS SCENARIO 2 - TOURISM ENHANCING

Table 1 shows the improvements on child mortality, unemployment and injuries due to the improvement of roads in the tourism enhancing scenario.

Table 2: Output KPIs - scenario 2

Constituency	Road density	Child mortality	Unemployment	Injuries
Arandis	0	- 6,6%	- 10,7%	+ 2,9%
Daures	+ 0,58%	- 3,0%	- 6,8%	0
Walvis Bay Rural	+ 0,90%	- 11,1%	- 9,4%	+ 7,4%
Daweb	0	- 2,0%	- 19,4%	0
Berseba	0	- 2,8%	- 4,8%	0
Karasburg West	0	- 5,7%	- 10,3%	+ 4,,%
Keetmanshoop Rural	0	- 1,3%	- 20,0%	0
Windhoek Rural	0	- 0,6%	- 1,5%	+ 4,5%
Khorixas	0	- 2,1%	- 6,4%	+ 2,3%

The figures show the change from 2011 to 2022 of tourism and GDP on country level.

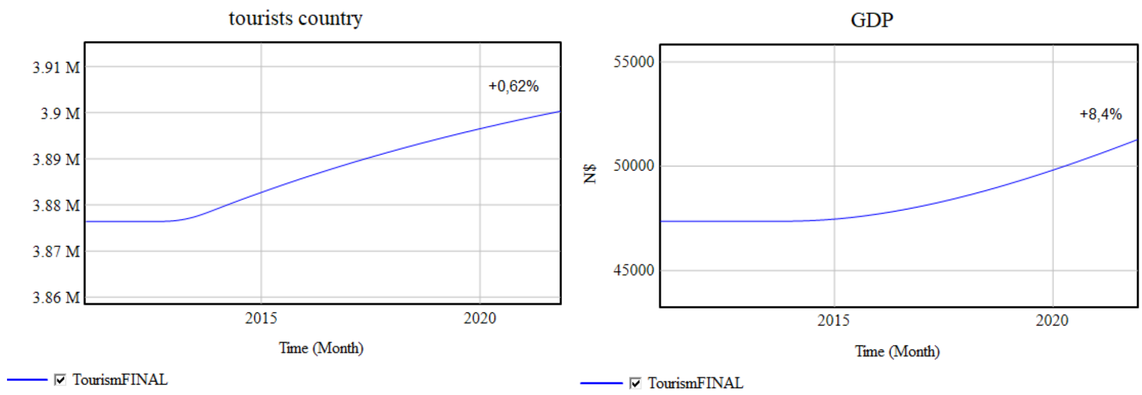

Figure 4: Increase of tourists and GDP in scenario 2

Both scenarios improve health, tourism and employment. The primary school enrolment rates remained the same over time for both scenarios. Road safety increases for both scenarios due to upgrades to bitumen, but the extent to which it increases depends on the extra measures that are taken with regards to road safety. It can be increased more by campaigns or more controls. Emissions go up in both scenarios, because emissions are a direct result of constructing and upgrading roads. The tourism scenario attracts more tourists because the roads between the major attractions are upgraded to bitumen. Both scenarios are realistic and might happen in the future. The scenarios can and might be combined.

Sensitivity analysis is conducted to assess the change of a parameter's behaviour when adding uncertainty to the model. For all parameters, the magnitude of the variables labelled as uncertainty (the effect of road infrastructure on economic growth and reversed) determines the extent of the growth. The structural behaviour does not change, but the parameters are quite sensitive to the addition of these uncertain relations. This makes sense, since the feedback loop is self-reinforcing; if for instance new roads are constructed, the economic growth will evidently increase, which increases building road infrastructure again.

IV. Conclusions and recommendations

In this study, a system dynamics model is developed which can be used to assess the effects of improvements in road infrastructure on the factors economic growth, road safety, emissions, education, health, employment and tourism. Besides, the relations between road infrastructure and the same factors are quantified for Namibia based on literature study and data-analysis. Lastly, two possible future scenarios for Namibia concerning road infrastructure are identified and used as input for the SD model, which showed the usefulness of the SD model and led to insights for the case of Namibia. These insights are discussed below.

MAIN INSIGHTS NAMIBIA

The main contributions and the insights for Namibia are (i) combining a large part of all available data from a large variety of sources; (ii) the identification of small but existing relations between road density and education, health and employment and between road quality and health and employment. It cannot be proven that tourism is road density or quality dependent. Looking at the number of tourists in each region, it appears that tourism is highly attraction based. It was found that most tourists highly value a good infrastructure and it is their number one remark on improvement for tourism in Namibia. Supported by literature and the framework, tourism would benefit from a better road network, and (iii) health, employment and tourism would benefit of the improvements of roads in both identified scenarios. Namibia is pursuing its ambition of becoming the logistics hub of Southern Africa by 2022. In this scenario, the roads belonging to the four corridors connecting Walvisbay Port to the hinterland on the concerning constituencies are upgraded to dual carriageway. The results are that health, employment and tourism would benefit of the improvements of these roads. Dependent on the effort on increasing road safety, this scenario could also decrease the number of road crashes and therefore injuries and fatalities. Injuries and fatalities are found to have a large impact on the GDP. The second scenario drawn for the Namibia case is that of enhancing tourism. The outcome of this scenario is that tourism would be increasing if the roads between the four major natural attractions are improved in terms of quality. Besides, both health and employment benefit from these upgrades; the U5MR and unemployment rate decrease in all constituencies the roads connecting the four attractions pass.

LIMITATIONS
The main limitation of this research is the limited availability or even a lack of data made this research difficult and this probably applies to most researches on developing countries. If more or better data would have been available, a different approach with better accessibility metrics could have been used. This research revolves around road density as a metric, which is - as established before - not a comprehensive and strong indicator for the road infrastructure in Namibia, mainly due to largely uninhabited areas without road infrastructure. This makes it difficult to draw conclusions and to predict effects of future scenarios. However, when being aware of the difficulty and complexity of road density as an indicator, conclusions are still useful. Predictions of the effects of a future scenario remain uncertain, but due to the extensive research that has been done on many facets, the insights gained in this study can still be considered useful and reliable.

A second limitation is the number of assumptions that are made regarding linear relationships between education, health and employment and road density. Assuming a linear relation between variables requires a high generalisation. Averages are taken of all constituencies to gain insights in the relation between two variables, which means that - in this research' case - different performances for similar road density smooth to one equal performance. By doing this, all constituencies are affected equally by more or better roads, where one would expect to have a bigger difference for constituencies with a current poor performance. Other shapes than linear relations were tested, but were not found to be significant with the used data. The biggest reason for this is probably the usage of road density as a metric. It became clear that this is not a very strong indicator, mostly due to large uninhabited areas which are counted in the road density metric. Ideally, better data would result in a more suitable and representative indicator of the road infrastructure, for instance the accessibility to different facilities in terms of time or distance. With this, the data analysis would probably be more accurate too and in this case, multiple regression analysis would give representative results. As for the data analysis done in this research, the identified relations do not serve as entirely valid and realistic relations, but they do indicate a relation which complies with literature. Therefore, it was still useful for the SD model, with the note that it should be considered to serve the purpose of facilitating *insights* in the dynamic system of road infrastructure and all factors and not a given and definite relation.

FURTHER RESEARCH
Four recommendations for further research have come forward. Firstly, as this research proposed a method for developing countries, this method can be applied to many of these countries. Once more countries are researched, the outcomes could be compared or combined as well. For instance, for Namibia it would be interesting to know the effects of road infrastructure on the factors in neighbouring countries South Africa, Botswana, Zambia, Zimbabwe and Angola. The combination should include the logistics hub 2022 ambitions to see what the effects are on the whole region and if it has extra benefits. Secondly, a lot of assumptions are made on different factors and variables due to the scope and time limitation. Each factor and relation between factors and road infrastructure could be investigated more and more extensively. For instance it is not taken into account if there is a difference in quality in health services (hospital, clinic, health service, etc.) or in the capacity of both health care facilities and education facilities. Another example is the fact that there was no data available on locations of jobs and other determining variables for employment.

Thirdly, the research only included correlations now which do not indicate direction. It is well-founded to assume causality based on literature study, but it would be better if causality could be investigated. This could be done by having data from different moments in time. For Namibia, this would be relatively simple since they have census data every 10 years. This implies that solely extra information over time on road infrastructure is needed. Hence, the road length and quality in Namibia should be recorded over time, so that changes can be determined. Now it was only possible to find this road length and quality of one moment in time.

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Abbreviations

ABM	Agent-Based Modelling
AEP	Adult Education Programme
CLD	Causal Loop Diagram
EDI	Education for All Development Index
DBST	Double Bituminous Surface Treatment
GDP	Gross Domestic Product
GHG	Greenhouse Gas
GIS	Geographic Information System
GIZ	Deutsche Gesellschaft für Internationale Zusammenarbeit
HDX	Humanitarian Data Exchange
HOT	Humanitarian OpenStreetMap Team
HPP	Harambee Plan for Prosperity
ICT	Information and Communication Technology
KPIs	Key Performance Indicators
LAC	Legal Assistance Centre
LUTI	Land-Use and Transport Interactions
MDGs	Millennium Development Goals
MoWT	Ministry of Transport and Works
MSME	Micro, Small and Medium Enterprises
NAC	National Airport Company
Namport	Namibian Port Authority
NDP	National Development Plan
NGO	Non-governmental organization
NPC	National Planning Commission
NSA	Namibia Statistics Agency
OSM	OpenStreetMap
PSE	Primary school enrolment
RA	Roads Authority
RD	Road Density
RFA	Road Fund Administration
RUCS	Road User Charging System
SADC	Southern African Development Community
SD	System Dynamics
SDGs	Sustainable Development Goals
TEU	Twenty-foot Equivalent Unit
TFP	Total Factor Productivity
TVET	Technical, Vocational Education and Training
U5MR	Under-Five Mortality Rate
UNAM	University of Namibia
VIF	Variance Inflation Factor
WEF	World Economic Forum

1
Introduction

There has been a remarkable progress in the world in terms of poverty reduction and the combat towards undernourishment the past decades (Roser & Ortiz-Ospina, 2018). However, there is a need for even more improvement. One way to enhance economic growth in a country is to improve transport infrastructure (Lakhera, 2016). Nonetheless, there is little research on the dynamics around these improvements and their effects on other socio-economic factors.

As of today, 783 million people live below the international poverty line of US$1.90 a day and 815 million people are undernourished (United Nations, 2018e). In the Brundtland report, 'sustainable development' is defined as "humanity has the ability to make development sustainable to ensure that it meets the needs of the present without compromising the ability of future generations to meet their own needs" (World Commission on Environment and Development, 1987). Despite its ambiguity and malleability, a more clear fixed and immutable meaning remains elusive (Kates et al., 2005). However, the United Nations attempted to improve the situation across the globe while tackling climate change by establishing the Sustainable Development Goals (SDGs). These SDGs aim to achieve each goal and target by 2030. The SDGs consist of seventeen goals which address the global challenges we face, such as poverty, inequality, climate, prosperity, peace and justice (Friedrich, 2016).

The eighth Sustainable Development Goal is 'decent work and economic growth' (World Bank, 2017). Researches acknowledge the substantial impact of infrastructure on the Gross Domestic Product (GDP) and economic growth (Canning & Pedroni, 2004; Crescenzi et al., 2016; Esfahani & Ramírez, 2003; Hu & Kauppila, 2013), and specifically the impact of transport infrastructure on economic growth (Achour & Belloumi, 2016; Garcia-Milà & McGuire, 1992; Hulten & Schwab, 1991; Lakhera, 2016). Part of the researches emphasise the difference in impact of transport infrastructure on economic growth between developed and developing countries. Fuente (2010) concludes his research with "appropriate infrastructure provision is probably key input for development policy". According to Lakhera (2016), transport infrastructure and the technology revolution around transport can ensure that growth is inclusive, it provides high social rates of return, even more so in low-income countries and could play an important role in the economy and industry of low-income economies. Due to limited expenditure, big investments such as infrastructure investments are fundamental and crucial for developing countries. It would be desirable to have more insight in the exact effects that investing in transport infrastructure has on socio-economic factors within a country. There is a limited amount of research on the effects of transport infrastructure in developing countries on these factors. Also, most researches have investigated one single effect of transport infrastructures or imposed challenges of each separate factor as a static relationship. Since most governments of developing countries only have a limited expenditure and have to make fundamental choices with regards to investments in certain sectors, it is very important to be able to get more insights in these effects. The objective of this thesis is twofold; firstly it *aims to develop a method to investigate the effects of an improved road network on health, education, employment and tourism in developing countries* and secondly *to apply this method to the country Namibia.* Namibia is a developing country in Southern Africa which is independent since 1990 and with capital city Windhoek.

The remainder of this introduction gives an overview of the research that is performed. Firstly, the research questions are presented, which is followed by the research approach that is followed to answer the research *questions. Within the research approach, different methods are identified that are used to conduct this research. Thirdly, the data that is used for this research is briefly explained. The last sections elaborate on the scope of this research and provide a reading guide.*

1.1. Research Formulation

There is a lack of knowledge and research on the effect of an improved road network on attributes such as health, education and employment as a whole dynamic system. It seems that the Namibian government is not currently aware of the exact effects of improving road infrastructure and of the trade-offs policy-makers make between positive and negative aspects of this improved road infrastructure when deciding to invest in road infrastructure. In order to possibly change the focus on road transport towards a more sustainable transport infrastructure and transport behaviour, awareness of and insights in the effects and consequences is needed. Policy-makers can make substantiated decisions when having all information. Therefore, the research questions of this research are:

1. *What are the relations between road infrastructure, road safety, emissions, economic growth, education, health, employment and tourism based on literature?*
2. *What is the socio-demographic status of Namibia and how does the current road infrastructure affect this?*
3. *What is the current transport infrastructure situation in Namibia?*
4. *What are the relations between road infrastructure, road safety, emissions, economic growth, education, health, employment and tourism in Namibia?*
5. *What are possible underlying explanations for constituencies with similar road densities and discrepant performances on the factors?*
6. *What model is developed to investigate the effects between road infrastructure, economic growth, road safety, emissions, education, health, employment and tourism in Namibia in future scenarios?*
7. *What are possible future scenarios for Namibia that include road infrastructure improvement and how do they affect education, health, employment, tourism, emissions, road safety and economic growth?*
8. *How does this research apply to other developing countries?*

1.2. Research Approach

The aim of this research is to answer the research questions by investigating the influence of road infrastructure on certain factors underlying economic growth, such as health, education and tourism in Namibia. The overall methodology for this thesis is a Systems Engineering (SE) methodology. This methodology originates in the 1930s, but an introductory and clear book on SE has been written by Sage & Armstrong (2000). SE is a discipline or a way of thinking that manages problem solving processes in the context of socio-technical questions. It looks at a problem in its entirety, and aims to enable the realisation of successful systems (INCOSE, 2007; Züst & Troxler, 2006). Sage & Armstrong (2000) introduce the concept of 'Systems Engineering life-cycle', which can take many forms, dependent on the application of SE. Therefore, the research flow used for this research (figure 1.1) is partly based on their 'seven steps of the logic dimension of systems engineering'. The final research flow is partially adjusted and extended to fit this research approach in the most suitable way. The authors identify three phases: definition, development and deployment. The three phases and the related chapters are illustrated in figure 1.1.

Recent developments in terms of digitisation and computational progress - mostly in terms of data availability and the big data concept - have initiated an interesting split in modelling approaches. Where the more traditional, model-driven approach heavily rely on the (tacit) knowledge and experience of the modeller, data-driven models are more reliant on the actual outcomes and insights that can be obtained from big data-sets. Still, data cannot serve as a solution or answer to complex problems and it is only useful when it is interpreted and used appropriately. This can be done by embedding data in a proper theoretical framework in which data can provide useful insights and theory can explain relations and substantiate assumptions.

Therefore, this study uses a **data- and theory-rich modelling approach**. Theory from literature is used to define how data is used in the model, the actual mechanisms of the system and the interrelations between different factors. Since the transport infrastructure situation and the socio-demographic situation differ extensively per country the decision is made to use a case study to carry out this research. The research will be focused on Namibia, a country in Southern Africa. Data is used to - where possible - identify relations between the factors in Namibia based on some given and some self-gathered data-sets.

Methods

To answer the research questions, different methods are used. For this research, three research methods will be used, namely: (1) Literature research, (2) Spatial data analysis case study, and (3) System Dynamics. The list below gives a brief introduction of the different methods.

1. **Literature research**
   A literature review can be used for "understanding of the topic, what has been already done on the topic, how it has been researched and what the key issues are" (Hart, 2018). Literature research is used to get an overview of the research available on this topic and to bound the research. The main constraint of using literature research as a method is that it can get too theoretical. However, since this research uses a case study and extensive data analysis of this case study and the literature research builds up to that, it is not believed to be too theoretical. The literature study aims to give information about all the facets this research has something to do with and to identify research or knowledge gaps. Literature is found through online databases of scientific research, which are either controlled (Scopus, Science Direct and Web of Science) or uncontrolled (Google Scholar). Controlled database sources can be unreliable with regards to citation and metrics and controlled databases have less research available and have less subject specific sources compared to Google Scholar (Halevi et al., 2017). Since this research includes so many different facets, there are many used search words. However, the main keywords used for the search are 'accessibility', 'road infrastructure', 'education', 'health', 'employment' and 'tourism'. Furthermore, this study is established by making use of the snowball technique, which indicates that one follows the references from bibliographies from sources that are read (Ridley, 2012). This enables the researcher to discover new research.

2. **Spatial data analysis case study**
   To identify the relationships between road infrastructure and the different factors, data has to be analysed and correlated using data analysis. Since the available data is related to a geographical location (a constituency), the available data is called spatial data. Chapter 4 elaborates on the specific test (multiple regression) that is used to investigate the relationship between road infrastructure and the factors.

3. **System Dynamics**
   Various modelling techniques could be used for addressing the issue. One of these techniques is System Dynamics (SD), which is a method "to describe, model, simulate and analyse dynamically complex issues and/or systems in terms of the processes, information, organisational boundaries and strategies" (Pruyt, 2013). The fundamental principle of SD is that structure determines behaviour (Brailsford, 2008). It is a commonly used approach to model nonlinear behaviour of complex systems over time and allows one to design policies which improve performance (Forrester, 1997). The high level of aggregation makes SD an appropriate modelling method to model global and national issues, which makes modelling the interaction between road infrastructure and economic growth and its underlying factors and mechanisms with SD very suitable. However, SD is not an obvious choice for problems with a significant spatial factor, such as road infrastructure. Developments are taking place in for instance the coupling of Geographic Information Systems (GIS) to SD software (Neuwirth et al., 2015). Whilst working on this thesis, the Anysim software was developed, which is a cloud-based simulation software supporting multi-scale incorporating system dynamics modelling, agent-based modelling (ABM) and discrete-event simulation (AnySim, 2019). This multi-method software would be very suitable for further research in the area of this study. Manually coupling software or modelling methods adds complexity in terms of implementation to the process, while also significantly decreasing model manageability in terms of simulation time. Therefore, it might be more beneficial to explore the possibilities of implementing a spatial factor in SD itself. The input for the SD-model is a combination of the literature study and the spatial data analysis. All relations that can be identified from the available data are

used and confirmed by literature. The relations that cannot be identified based on data are taken from literature.

1.3. Scope

The list below shows the choices for the scope of this thesis.

- The thesis focuses on the case of Namibia. However, the identified steps are applicable to other developing countries (with similar characteristics).
- The focus is on the road network in Namibia only. This specifically includes the upgrading the roads to bitumen and new gravel or bitumen roads in Namibia. The choice for looking at the road network only is motivated in chapter 3.
- The road sector in Namibia is quite complex in terms of different parties and stakeholders involved. It is difficult to write this research from one of the parties, since most investments are done through a joint collaboration of funding (Graig, 2018). Therefore, the research will be written from the perspective of the full road sector, which includes the Ministry of Works and Transport, the Roads Authority and the Road Fund Administration.
- The following factors will be used in this research: health, education, tourism, employment, road safety and emissions (this will come forward in chapter 2 and 3). This research investigates the effect of an improved road network on these factors.
- The feedback loop that serves as a basis for this study goes from road infrastructure to economic growth and back. Underlying to the effect of road infrastructure on economic growth are the explained factors. Both these relations are seen as *uncertain* in this study. Economic growth itself influences (some of) these factors as well, but due to the transportation perspective of this research, these relations are not taken into account.

1.4. Contributions

This section discusses the contributions of this research, both scientifically as societal. Firstly, scientific contribution can mainly be found in the provision of a method to investigate the effects of road infrastructure on social factors in developing countries. Using multi-scale modelling in system dynamics is something that has not been researched yet and there are no scientific publications on it. Therefore, this research contributes to a gap and presents an innovative way of including spatial concepts in system dynamics. Also, this is the first research to look at the effects of road infrastructure at such a highly aggregated level to capture a comprehensive overview of multiple factors.

The societal added value of this research is very high. By investigating developing countries in general, there is an attempt of contributing to the development of such countries. Besides, this study focuses on the social factors such as education and health which is of great importance in general an all the more in developing countries. Many of these countries would benefit of improved education, health, employment and tourism.

1.5. Reading Guide

This section provides the reading guide for this research. Figure 1.1 shows a research flow in which the sequence of the chapters can be seen as well.

- Chapter 2 provides general and broader background information on transport infrastructure and the effects of transport infrastructure by reviewing existing literature. The result is a theoretical framework which shows all identified relations.
- Chapter 3 gives an extensive overview of Namibia as a country. It focuses on both the socio-demographic status of Namibia as on the transport situation.
- Chapter 4 aims to identify the relations between road infrastructure and education, health, employment and tourism based on census data. In the chapter the data handling process is briefly described and multiple regression analyses are performed.

- Chapter 5 develops the SD-model by describing all model components with their causal relations.
- Chapter 6 provides insights and explanations of certain behaviour behind the data. Four constituencies with similar road density value are investigated and discussed.
- Chapter 7 identifies future scenarios in terms of road infrastructure construction or upgrading. With the help of the model, the performance on several KPIs for each constituency can be assessed.
- Chapter 8 answers the research question by concluding the research, provides recommendations for further research and gives limitations of the performed research.

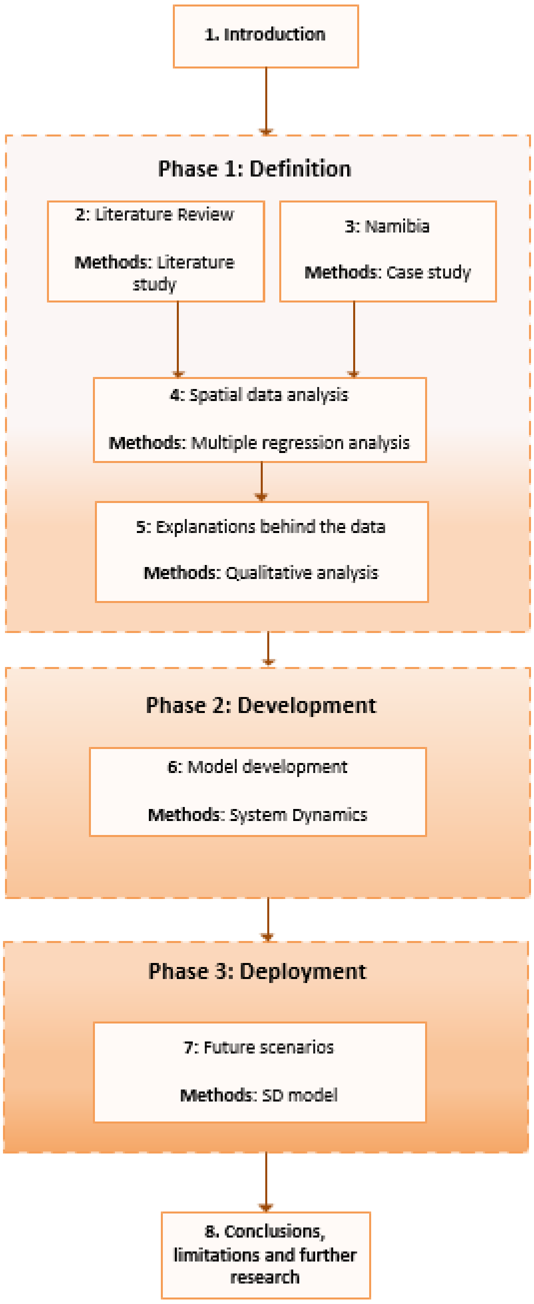


Figure 1.1: Research Flow

2
Literature Review

This chapter aims to give an overview of the literature on how transport infrastructure contributes to the economic growth and underlying socio-economic factors in developing countries. With this overview, the first research question "What are the relations between road infrastructure, road safety, emissions, economic growth, education, health, employment and tourism based on literature?" is answered. The first section elaborates on the sustainable development and the role of transport infrastructure in this development. Secondly, section 2.2 substantiates on the research that has been done on the relationship between transport infrastructure investment and economic growth. Section 2.3 explains the concept of accessibility and how to measure it. This section also elaborates on factors underlying the relationship between transport infrastructure and economic growth that are relevant for developing countries and how these factors are affected by improved accessibility. Section 2.4 describes the relationship between road infrastructure and road safety and section 2.5 between road infrastructure and emissions. Figure 2.1 shows an overview of all discussed factors affected by road infrastructure. This framework is established after an extensive literature research on all different factors. If a relation between factors is not shown in the figure, there is no significant research found on that relation. The effects of economic growth on education, health, employment and tourism are not taken into account in this research due to the scope. Section 2.6 substantiates on different methods that can be used to capture spatial dynamics. Subsection 2.7 expands on similar research that has been done and lastly section 2.8 summarises the literature review and gives an overview of the results.

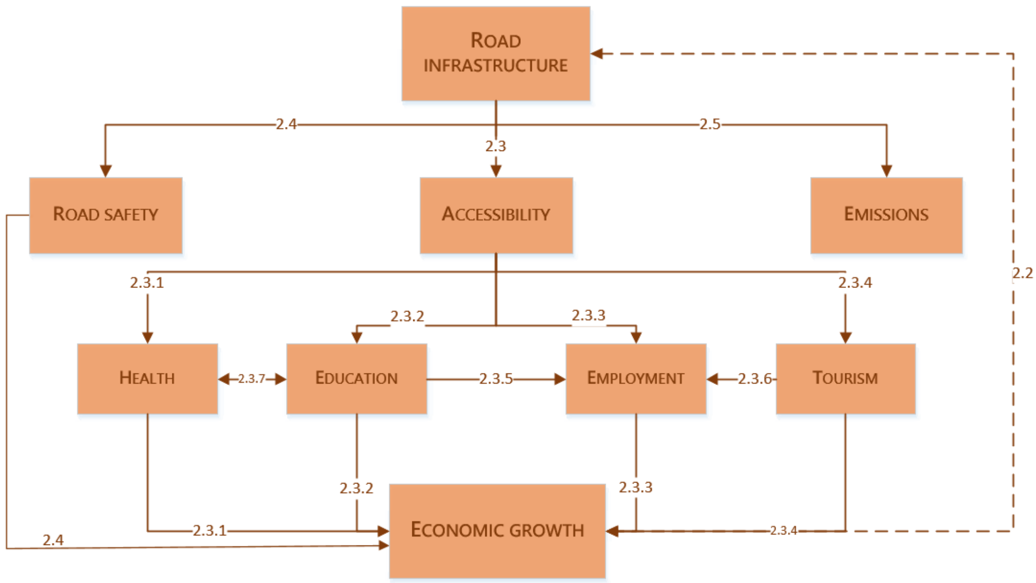


Figure 2.1: Overview of literature research

2.1. Sustainable Development

In the Brundtland report, sustainable development can be defined as "humanity has the ability to make development sustainable to ensure that it meets the needs of the present without compromising the ability of future generations to meet their own needs" (World Commission on Environment and Development, 1987). Despite its ambiguity and malleability, a more clear fixed and immutable meaning remains elusive (Kates et al., 2005). However, the United Nations attempted to improve the situation across the globe while tackling climate change by establishing the Sustainable Development Goals (SDGs). These SDGs aim to achieve each goal and target by 2030. The SDGs consist of seventeen goals which address the global challenges we face, such as poverty, inequality, climate, prosperity, peace and justice (Friedrich, 2016).

Using improvement of transport infrastructure to achieve development in developing countries is in accordance with these SDGs (the eighth SDG). An extended research on the impact of transport infrastructure on economic growth has been done by Pradhan & Bagchi (2013), using macroeconomic data of India. They conclude that a bidirectional causality exists between road transport infrastructure and economic growth. Road transport positively influences the economic growth through the production process. Economic growth enhances road transport investment due to expansion in the manufacturing sector and a higher disposable income has increased demand for better road infrastructure. Fuente (2010) summarises that evidence in literature shows "that there are sufficient indications that public infrastructure investment contributes significantly to productivity growth". The overall conclusion seems to be that there is a positive impact of transport infrastructure (investment) on the economic growth. However, Melo et al. (2013) conclude in their meta-analysis that "the productivity effect of transport infrastructure can vary across main industry groups, tend to be higher for the US economy than for European countries, and are higher for roads compared to other modes of transport". Section 2.2 elaborates on different analytic approaches for investigating this relationship.

Part of the researches emphasises the difference in impact of transport infrastructure on economic growth between developed and developing countries. Fuente (2010) concludes his research with "appropriate infrastructure provision is probably key input for development policy". According to Lakhera (2016), transport infrastructure and the technology revolution around transport can ensure that growth is inclusive, it provides high social rates of return, even more so in low-income countries and could play an important role in the economy and industry of low-income economies. Likewise, Candelon et al. (2013) conclude that public transport infrastructure investments are likely to be beneficial for developing countries[1] in particular. Besides the multiple links between infrastructure and development they highlight, The World Bank's landmark World Development Report 1994 emphasises how policy can improve not only the quantity but also the quality of infrastructure services in developing countries (Fedderke & Bogetić, 2009; World Bank, 1994). Furthermore, most developing countries do not have an advanced transport infrastructure network such as developed countries often do have (Sperling, 2002). Therefore, there is a lot to gain and influence in these countries with regards to transport, transport policies and transport investments. Hence, this research focuses on the transport infrastructure in developing countries. Transport infrastructure affects more factors than economic growth. This will be elaborated on in section 2.3.

2.2. Transport infrastructure and economic growth

This section aims to give an overview of the existing literature on the influence of investing in transport infrastructure on economic growth and vice versa and the underlying factors.

The influence of transport infrastructure on economic growth

Lakshmanan (2011) identifies three common analytic approaches to investigate the effect of transport infrastructure on economic growth:

1. **Micro-economic**
2. **Macroeconomic**
3. **Broader consequences of transport capital**

[1] The United Nations annually publish a country classification of developing countries (United Nations, 2018f)

Micro-economic This approach looks at the smaller level of transport improvements leading to lower transport costs. Examples of such improvements are reduced and predictable travel times and the consequent lowered vehicle operating costs. According to Lakshmanan & Anderson (2002), "the eventual consequences of such dropping transport costs include lower product prices, increasing product demand, and a higher level of economies of scale, which in turn lead to further cost reductions and output growth". Transport improvements are suggested to enable restructure logistical systems and therefore have significant indirect effects on firm competitiveness. This is supported by several researches, mainly in empirical research. Lewis (1995) employed an intensive interview technique on a small sample of firms to measure the production benefits of a general reduction in freight travel times. The interviewees - managers of firms in a variety of production sectors - were asked to speculate as to if and how reduced travel times would affect reduction in logistics costs. Due to the small sample size, results should be interpreted and used with caution, but the general conclusion is that the value of reduced travel times depend on the industry and only a portion of total savings can be derived from reduced transportation costs as a result of transport improvement. A second empirical research is performed by Shirley & Winston (2001). They find empirical support for the hypothesis of lower transportation costs and higher reliability allowing firms to maintain lower inventories. However, their results show that, for each dollar of infrastructure spending, the marginal inventory reductions are declining over time. A major assumption that is made in the context of most researches is that the firm's level of production is independent of freight transportation costs. This would make expanding the geographical scope of their markets easier and thus increasing output and demand. However, competition over space "may lead to regional specialisation which yields improvements in aggregate productivity" (Lakshmanan & Anderson, 2002).

Macroeconomic The core of this approach is to relate transport infrastructure investments to GDP in the economy. This approach views infrastructure as a direct injection to the economy. "In this form, it is possible to observe whether and to what degree infrastructure increases the level of economic output and enhances the productivity of private capital" (Lakshmanan & Anderson, 2002). Most studies acknowledge the existence of this economic relationship, whereas the magnitude of the relationship between transport infrastructure investments and economic output varies widely across studies. The first extended research on this relationship was done by Mera (1973). He found that a 1% increase in infrastructure stocks leads to respectively 0.35% and 0.4% increases in the outputs of Japanese manufacturing and service sectors. The most acclaimed research on this effect is done by Aschauer (1989). His research shows that "the annual percentage changes in total factor productivity due to public capital estimated from the coefficients of his production function turn about to be large". However, the years after his publication, several researches criticised the use of aggregate time series data that Aschauer used. First of all, data may create a spurious relationship between production inputs and output since they both tend to grow over time (Jorgenson, 1991). Secondly, there might be a delay in time between the construction of the infrastructure and the actual use of it. This could make the estimates obtained from time series data about productivity unreliable (Aaron, 1990). Thirdly, some critics suggest that public infrastructure makes little to no contribution to the overall economy (Hulten & Schwab, 1991). As a response to this, Nadiri & Mamuneas (1996) developed a more sophisticated macroeconomic model which incorporates demand and supply factors explicitly. They applied the model to several countries and the outcomes differ for the same country overall, and at different periods of time, for different countries at comparable stages of development and for countries at different stages of development. The main conclusion of using this analytic approach is that there is a widespread support for the view that transport infrastructure investment contributes to the economic growth and productivity. The magnitude of this relationship remains unknown, which reflects transport's spill-over characteristics. A criticism to this approach in general is that the specification of impacts of transport infrastructure on production factors - such as labour, capital and other factors - in macroeconomic models remains too aggregate to be more than a 'black box' (Lakshmanan & Anderson, 2002).

Broader consequences of transport capital This approach attempts to capture the effect of transport infrastructure investments on economic growth through various mechanism which translate the improvements of the investments into impacts rippling through the economy. These effects interact with one another and the total of these effects translates in the growth of total factor productivity (TFP) in the economy. This approach is majorly focused on the general equilibrium theory, which considers the simultaneous general equilibrium of *all* markets in the economy by explaining the behaviour or supply, demand and prices in a whole economy. The theory seeks to prove that the interaction between those factors will result in an overall general equilibrium (Levin, 2006). Lakshmanan (2011) organises the underlying mechanisms in four categories: (a) gains from trade, (b) technology diffusion, (c) coordination device and the 'big push' and (d) gains from agglomerations, which are made possible by transport. The main point is that better transportation mostly leads to more gains from trade and can lead to major shifts in technology that bring improvements in aggregate efficiency. This approach looks at the effect of transport infrastructure investment on economic growth from a broader perspective than the previous two, but is still solely focused on purely economic effects.

Concluding there is a lot of research on the effect of transport infrastructure investment on economic growth. The most used analytic approaches in research are the micro-economic and the macroeconomic - the 'conventional' transport modelling methodologies - which are oriented toward achieving a supply/demand equilibrium. "This requires assumptions that are difficult to satisfy in reality" (Abbas & Bell, 1994). This is one of the reasons that one can see a shift from these conventional approaches of investigating the effect of transport infrastructure on the economic growth towards newer approaches. The presence of dynamics in the relationship between transport infrastructure investment and economic growth is acknowledged and more researches attempt to capture the effect in a more dynamic way. The third - general equilibrium approach - attempts to capture a broader context, more than solely economic principles such as reduction in production costs, transportation costs or inventory costs. However, there is little research on the underlying socio-economic factors. Most researches as discussed above have an entirely economic approach and leave out the more social factors such as health and education. This research will attempt to fill that gap in literature by researching the effect of road infrastructure investment specifically on socio-economic factors such as health, education, employment, tourism, road safety and emissions. This study looks at the relation between road infrastructure and economic growth on a highly aggregated level and therefore cannot take all underlying mechanisms and factors into account. The main focus is on the socio-economic factors and how they explain part of the relation between transport infrastructure and economic growth.

The influence of economic growth on transport infrastructure

The influence of economic growth on transport infrastructure is not as widely discussed and investigated as the relation from infrastructure to economic growth. Not all researchers acknowledge a significant causal relation between GDP and transport infrastructure. The relation depends on the context (case-study), but also on the type of infrastructure. Pradhan & Bagchi (2013) find that economic growth results in the expansion of the commercial and industrial sector - mainly in the manufacturing sector - and to facilitate this, road transport would be basic input. Besides, higher disposable income (related to GDP) increases demand for better infrastructure to enable household entertainment. This study has been done in India and is on road infrastructure in specific. Perkins et al. (2005) researched the effect of different types of transport infrastructure on the GDP and vice versa in South Africa. They found that roads have the biggest impact of all transport infrastructures on GDP, but GDP does not significantly influence the (investment in) road infrastructure. The effect is highly context dependent and decision-makers or policy-makers have a high influence on the actual potential increase in road infrastructure when experiencing economic growth. Therefore, this relation is labelled as *uncertain*, which means that the relation is not able to be relied on, not known or not definite. The uncertain relation is indicated by a dashed line. The effect of road infrastructure on economic growth remains elusive as well, because it is unknown what part of the effect of road infrastructure on economic growth is explained by the identified factors. Hence, there is a bidirectional uncertain relation between road infrastructure and economic growth.

2.3. Accessibility

Transport infrastructure in general can be seen as a socio-technical system. The term socio-technical system describes "systems that involve a complex interaction between humans, machines and the environmental aspects of the work system" (Baxter & Sommerville, 2011; Emery et al., 1960) or "systems that involve both complex physical-technical systems and networks of interdependent actors"(de Bruijn & Herder, 2009). With the physical, technical aspects of transport infrastructure and its effects on humans, society and environment in a society or country, this can be labelled as a socio-technical system. There is not one uniform international definition of transport infrastructure. One major aspect is which modes transport infrastructure includes. The European Commission determines that transport infrastructure entails rail, road and inland waterways, where the Glossary of Transport Statistics gives a general definition on airports and seaports as well (Hu & Kauppila, 2013). Chapter 3 elaborates on the choice for investigating the effects of road infrastructure only and therefore the remainder of this research focuses on road infrastructure specifically. Rails, airports and ports will be left out from here. This thesis aims to investigate the effect of improved road infrastructure in Namibia on several factors, among which are health, education and employment. To model the effect on these factors, the accessibility of certain services to individuals must be measured. Namibia as a country differs from countries where most transportation research is done, mostly by its population density. Namibia is one of the lowest densely populated countries in the world and the largest part of the country can be considered as rural. This section therefore focuses on literature on accessibility measurement in general and in Namibia in specific.

Defining accessibility

The positive effect that road infrastructure has on economic growth and development, can be explained by accessibility. Accessibility is generally referred to as the ease of reaching opportunities (Chen et al., 2012; Papa & Coppola, 2012); land-use activities (Dalvi & Martin, 1976; Koenig, 1980); economic activities (Song, 1996); valued destinations (El-Geneidy & Levinson, 2006); activities such as work, shopping, and health care (Luo & Wang, 2003); and often-visited places (Cervero et al., 1999). The transportation definition of accessibility is often given as "the ease which any land-use activity can be reached from a location using a particular transport system" (Koenig, 1980). Briceño-Garmendia et al. (2015) explain that "the level of accessibility provided by a specific road network is a key component of poverty reduction, economic development, and increased shared prosperity." They further elaborate that readiness of the road network for a natural disaster or any unpredictable event would ultimately translate into reduced poverty and economic development. Most transportation accessibility studies break down accessibility into two components being (similar to) availability and proximity (Joseph & Phillips, 1984; Luo & Wang, 2003; McGrail & Humphreys, 2009). Geurs & van Wee (2004) however, use four components to describe accessibility. The list below describes the components as identified by Geurs & van Wee (2004).

1. *Land-use component:* reflects the land-use system, which consists of supply, demand and confrontation of this supply and demand. The supply involves the amount, quality and spatial distribution of opportunities at each destination, such as health care, shops, jobs, schools, etc. Inhabitants at origin locations have a demand for these opportunities. Confrontation of this supply and demand may lead to competition for the opportunities of which some have a restricted capacity, such as jobs, schools and health care facilities.

2. *Transport component:* involves the transport system, in which the amount of time, costs and effort are of travelling are included. This can be conveyed as the dis-utility for an individual to make a trip from origin to destination using a specific transport mode. The supply of infrastructure is expressed in its location and characteristics. The demand relates to passenger and freight transport. In this research, freight is not taken into account and therefore, the demand will consist of passengers only.

3. *Temporal component:* reflects temporal constraints, mostly being the availability of activities, opportunities or services during the day and the time available for individuals to participate in these. This component is not the point of focus in this research and time limitations of certain activities of services will not be further taken into account.

4. *Individual component:* reflects the needs, abilities and opportunities of an individual. The needs are dependent on age, income, education level, housing and household situation, etc. The abilities depend on people's financial resources, their condition and the availability of infrastructures and transport modes. The opportunities depend on income level, educational level, etc.). The individual component, is of major importance in this research. In Namibia, great differences between individuals exist and this is for instance reflected in income, educational level and vehicle ownership.

Measuring accessibility

The components as discussed help defining 'accessibility'. This is followed by different approaches to measuring accessibility. Geurs & van Wee (2004) distinguish the following four approaches to measure accessibility: (i) Infrastructure-based measures, where the service level of transport infrastructure is the point of focus. Accessibility is evaluated by analysing (observed or simulated) performance of the service level; (ii) Location-based measures, describing the level of accessibility to spatially distributed activities. This is typically on a macro-level, for instance whether an individual is within 30 minutes travel time from health care facilities. These measures are often used in geographical studies. Accessibility is an attribute of specific locations expressing how easily these locations can be reached; (Dalvi & Martin, 1976; Kwan, 1998; Song, 1996). (iii) Person-based measures, analyses accessibility from an individual's perspective. Limitations on an individual's freedom of action is measured in a space-time geography. This measure incorporates space-time constraints, such as time budgets or allowed travel speeds into the analysis. In this measure, accessibility is a property of individuals exposing how easily this individual can reach certain locations (Kwan, 1998). A feature of these measures is that they are able to distinguish accessibility patterns among different users of transport systems (Briceño-Garmendia et al., 2015; Kwan, 1998). This is very suitable for the situation in Namibia, where the differences between users are big, in terms of ownership of transport mode, income level, etc. The paragraph below substantiates on this measure; and (iv) Utility-based measures, calculating the economic benefits that individuals derive from the accessibility to the spatially distributed activities. The measure originates in economic studies.

Person-based measures According to Recker et al. (2001), "the spatial location and temporal availability of activity sites, together with the maximum speed an individual can travel between sites, establishes the individual's space-time prism; the volume of this prism encompasses the full range of possible locations at which an individual can participate." However, in this case time is a restriction of amount of hours in a day and opening hours of facilities, whereas in the Namibia case the main focus is the travel time for an individual to facilities such as health care, education or employment and how a reduction in this travel time impacts the population's health, educational level and employment rate. Secondly, Recker et al. (2001) focuses on how travel decisions can improve accessibility, whereas this research focuses on how enhanced road infrastructure can improve accessibility and therefore health, education and employment. Geurs & van Wee (2004) explain that "person-based accessibility measures are potentially very useful for social evaluations of land-use and/or transport changes", which in this research would be transport changes in the form of improved road infrastructure.

Improved transport infrastructure increases general accessibility. General accessibility enhances tourism, health, education, employment and disaster risk mitigation. Some of these effects influence each other as well. An overview of all relations as described below can be seen in figure 2.1. These effects are discussed in the sections below.

2.3.1. Health

Improving transport infrastructure evidently leads to a better access to health care facilities and thus an overall improved health situation (Fedderke & Bogetić, 2009). Better road infrastructure can lead to shorter distances from origin to destination, a better quality of the existing road and therefore enabling a shorter travel time and lower costs to reach health care facilities (Airey, 1991; Donnell O', 2007; Peters et al., 2008; Porter, 2010; Sperling, 2002). According to Queiroz & Gautam (1992) road transport plays an essential role in providing access to health, especially in developing countries. Schoeps et al. (2011) claim that "A long distance to health facilities has been shown to significantly reduce the use of health services by the population". They also found that in Burkina Faso, under-5 mortality rate (U5MR) was more than 50% higher at a walking distance of four hours compared with having a health facility in the village. Hence, "improved access to essential treatment holds great potential for significant reductions in child death." (Rutherford et al., 2010). An overall improved health has a positive effect on the economic growth of a country, mostly through the increase in life expectancy (Bloom et al., 2004). Improved accessibility by a better road infrastructure is obviously not *the* determinant of health and U5MR. When looking at child mortality, Hughes (2019) identified four main determinants for child mortality: childhood underweight, unsafe water and sanitation, indoor air pollution from household use of solid fuels and vehicle ownership and fatalities. The findings of this author are the result of a thirty year long research and the purpose of the research is to build a dynamic, global forecast system for international futures. During the work on the book, the team has found that income and education levels are so closely correlated across both time and countries that formulations using both variables can be unstable and therefore, generally only one of the variables is used in the model formulations. Therefore, the framework does not include income. Figure 2.2 shows an overview of the determinants - besides road infrastructure - of child mortality.

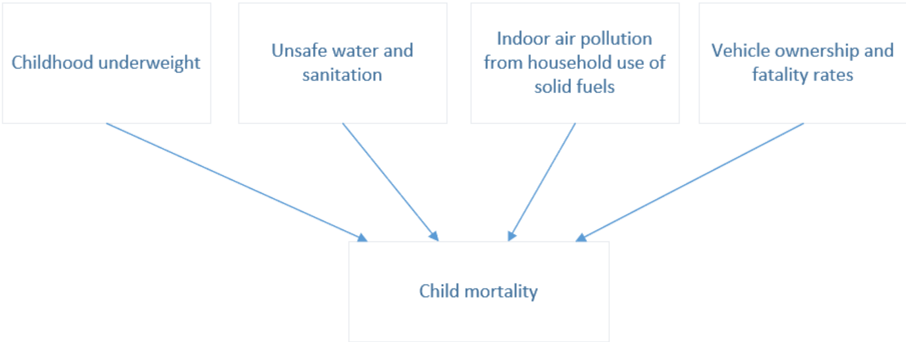


Figure 2.2: Determinants of child mortality other than accessibility

2.3.2. Education

Education retains similar benefits of an improved transport infrastructure. Improved transport infrastructure leads to a better accessibility of educational facilities (Porter, 2010; Sperling, 2002; Vasconcellos, 1997). Brenneman & Kerf (2002) found a positive influence of transport infrastructure on education of the save of time and effort which increases the energy and time to channel on education and easier access to schools, more access to cheaper and/or better goods and services, reducing environmental hazards that contribute to poor education and improving the delivery of education. Shrestha et al. (1986) conclude that topography is a particularly powerful determinant of educational participation in Nepal, with rugged areas with little roads and motorised transport. Siddhu (2011) found a similar effect of the distance to the nearest school being of significant effect on children attending second school. Besides, better accessibility improves the quality of education, which contributes to the economic growth of a country (Agénor & Moreno-Dodson, 2012; Hanushek & Wößmann, 2007). Obviously, higher accessibility through a better road network is not the actual determinant for education attendance. There are other variables of higher influence when determining education, although there is not one uniform conceptual framework of these determinants. The outcome is context dependent and scale or perspective dependent. Figure 2.3 shows a generalised framework found in literature based on research done by Huisman et al. (2010); Kabubo-Mariara & Mwabu (2007); Sattar & Zhang (2017), with factors influencing primary education enrolment apart from accessibility. Child characteristics

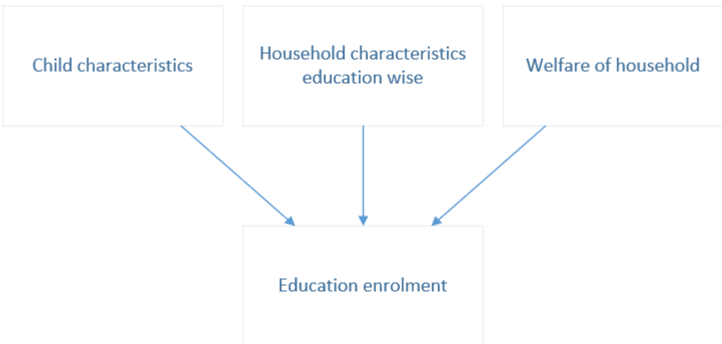


Figure 2.3: Determinants of education enrolment other than accessibility

include factors such as age and gender, household characteristics education wise include education level of household head/parents, employment parents etc. and household welfare includes parents' income and house characteristics.

2.3.3. Employment

The effect of improving transport infrastructure on employment is twofold: i) the direct increase of employment in construction of roads and the longer effect of employment in maintenance of roads and ii) according to several researches, a better transport infrastructure network gives an improved access to jobs (Sperling, 2002). Akinbobola & Saibu (2004) conclude that infrastructure-based policies initially reduce unemployment within the economy. The impact of employment on the economic growth remains ambiguous; there is not much literature on this specific relation. Economic growth and an increase in employment (or decrease in unemployment) often occur in accordance but the exact causality and the magnitude of this causality between the two factors remains undetermined. Accessibility through road infrastructure is obviously not the one major determinant of (un-)employment. (Pieters, 2013) developed a framework of the determinants of youth unemployment, which can be seen in figure 2.4.

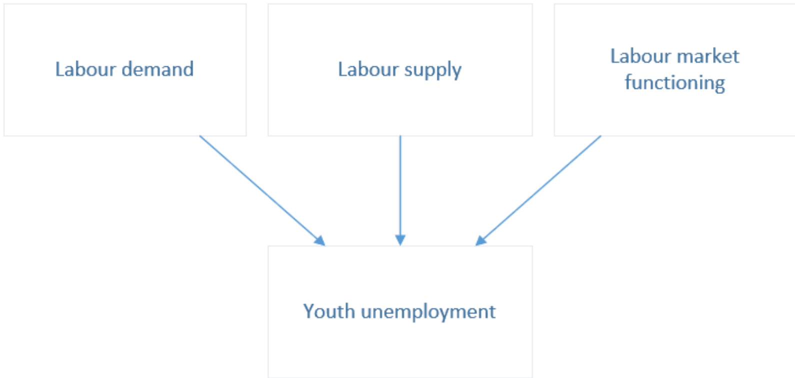


Figure 2.4: Determinants of youth unemployment

Labour demand includes the growth of productive yet labour-intensive activities and entrepreneurship. Labour supply includes equal access to education, quality of education, relevance of skills acquired in general education and VET, skill development for self-employment and employment in the informal economy and migration. The functioning of the labour market is defined by availability and quality of information,transparency in hiring practices and the labour market regulation.

2.3.4. Tourism

For many developing countries, the tourism sector forms a major contribution to the GDP and generates jobs (Fayissa et al., 2008; Lee & Chang, 2008; Liu & Wall, 2006). According to Khadaroo & Seetanah (2008), "Further analysis suggests that transport infrastructure is a more sensitive factor when travelling to African and Asian destinations. It is believed that tourists value the availability of efficient, reliable and safe travelling to relatively unknown destinations". In a different research, Khadaroo & Seetanah (2007) found a positive relation between tourism and transport infrastructure in Mauritius, Africa; the transport infrastructure of the island contributed positively to tourist numbers. They found a coefficient of 0,36 for total arrivals, which implies that a 1% increase in the stock of transport capital yields a 0,36% increase in arrivals in the island. Besides, tourism is found to be a direct driver of economic growth; Oh (2005) states that tourism-generated proceeds have come to represent - among other things - a significant revenue source. Many case-studies find a bi-directional relation between tourism and economic growth and some a unidirectional relation between both tourism and economic growth and vice versa (Lee & Chang, 2008). The latter relation (from economic growth to tourism) is not taken into account in this study due to the scope.

2.3.5. Education and employment

The relation between education and employment in developing countries is a complex relation and researchers tend to have different outcomes for similar tests in different developing countries. For instance, Boccanfuso et al. (2015) conclude that "quality improvements in higher education could have significant positive effects not only on the labour market outcomes of university-trained individuals, but also on the dropout rate on the university attendance". This research was only focused on the quality improvement and not on improvement of access to education. This result implies that there is a positive causal relation between education and employment. Guarcello et al. (2008) say that in general, higher levels of education are associated with an easier transition to work. However, for youth in Africa education does not necessarily reduce unemployment; in some countries unemployment among educated youth is exceptionally high. One can see that there is no uniformly identified and adopted relation between education and employment. The relation seems to be highly dependent on context, for instance the country, urban - rural areas and quality of education. Besides, the researches indicate that the level of education (primary, secondary and tertiary) is of influence in this relation. To determine this relation, one should use a case-study and see if there is a relation within that case-study.

2.3.6. Tourism and employment

The relation between tourism and employment is similar to the one between education and employment in the sense that there is no uniformly identified and adopted relation. In general, the tourism industry generates employment, foreign exchange earnings and direct investment, infrastructure development and income for island governments and the private sector (Lee et al., 2015; Mbaiwa, 2017). However, the ethics behind tourism jobs are disputable in terms of who gets the job, the rich or the poor and if it is the poor, the low wages they get are often quite problematic (Medina-Muñoz et al., 2016). Different researchers conclude various things, because this relation is highly context dependent.To determine this relation, a case-study should be used.

2.3.7. Health and education

The relation between health and education has been widely researched and is still a topic of interest. Studies elaborate on both the influence of education and health and vice versa. With regards to this first relation, Gwatkin et al. (2007) define education as one of the underlying factors of health. Furthermore, according to the second Canadian health report: "... literacy levels, which are usually, but not always, related to levels of education, are important predictors of employment, active participation in the community and health status. They are also important predictors of the success of a nation." (Health Canada, 1999). Most researches on this topic in developing countries highlight the positive impact of education and literacy on health (Bledsoe et al., 1999; Nussbaum, 2001). Kickbusch (2001) emphasises that not only these variables correlate, but also that the so called 'health literacy' is becoming increasingly important for both social and economic development. Secondly, Glewwe (2005) discusses the influence of health on education in developing countries. The relation is based on the idea that "poor health and nutrition among school-age children has a negative impact on their education". He states that this relation is very complex and difficult to estimate.

2.3.8. Disaster risk mitigation

Accessibility reduces the risk of a disaster. A disaster is very likely to occur once a hazard impacts a vulnerable situation (Khan et al., 2008; Maskrey, 1989; Wisner & Luce, 1993). In other words, disasters can be seen as a possible outcome of a hazard (Brooks, 2003). A majority of the developing countries is vulnerable to natural hazards due to the geographical location in zones highly susceptible (Alcántara-Ayala, 2002). An improved transport infrastructure network will decrease the overall vulnerability of a disaster of any group (community, region, country, etc.) (Masozera et al., 2007). According to Detges (2016), “the quality and extent of transport infrastructure influence the capacities of local communities to withstand extreme weather events”. Roads (i) allow drought-affected people to go to places such as markets and towns, where they have access to agricultural products, veterinary services, etc and (ii) can be used by NGOs and governments to deliver health-aid and food (Deligiannis, 2012). However, the impact of road infrastructure investment on this factor is difficult to measure as there are more underlying factors. Due to the limited time and information available, this factor will not be investigated in this research.

2.4. Road safety

A big issue with regards to road infrastructure is road safety. Safety is partly influenced by the material of the road infrastructure. For instance, gravel significantly reduces allowed and possible speed compared to bitumen. This influences the health care accessibility and possibly safety. Safety is either reduced because of higher speeds and hence higher risk of accidents or increased by a better condition of the road thus a lower chance of accidents (Figueroa et al., 2013). Hence, it is difficult to predict the exact effect of better and more infrastructure on safety. Bad road safety often leads to a high rate of road traffic deaths, which causes a reduce in life expectancy (Chandran et al., 2013). According to the WHO, 90% of crash facilities occur in low-income and middle-income countries (mostly developing countries) and extrapolations suggest that road traffic deaths will increase up to 87% in low- and middle-income countries between between 2000 and 2020 (WHO, 2009). Also, it is predicted that if no improvements with regards to road traffic safety are imposed, crashes will increase globally by 65% by 2020 (Peden & Toroyan, 2004). Road traffic injury has considerable impact on particularly low-income and middle-income countries. Injuries cost governments between 1%

and 3% of their gross national product (WHO, 2009).

2.5. Emissions

Building and maintaining road infrastructure involves quite some emissions. The emissions that – in general – come across road infrastructure are listed below:

- *Materials*: Hanson et al. (2012) researched the life-cycle of Greenhouse Gas (GHG) emissions of Materials Used in Road Construction. They estimate life-cycle emissions for production fuels, electricity production and aggregates. The emission depends on a lot of factors like the material itself, the ratio of the material and water, the expected service time life, the temperature under which the material is mixed, etc. Therefore, at this stage, no uniform statement can and will be done on how much emissions the material construction of asphalt causes. An extended literature review on - among other things - the CO_2 emission in asphalt mixtures is given in 'Asphalt mixtures emission and energy consumption: A review' (Thives & Ghisi, 2017).

- *Construction*: The on-site equipment during road construction can cause lots of emissions. The degree of emission depends on the type of construction work and the machine used for it (Kim et al., 2012). Hanson & Noland (2015) emphasise the difference in emissions of having a full traffic disruption or an intermittent traffic disruption.

- *Maintenance*: Part of the emissions during maintenance is caused by the traffic disruption. These emissions are relatively easy to decrease by planning road maintenance during the night and effective traffic management (lane closure, traffic diversion) (Huang et al., 2009). The emissions due to equipment and material used for maintenance are relatively low.

- *Extra vehicle movements*: Following the induced travel principle, increasing a certain transport network such as the road network (supply) increases the demand for that road (Noland & Lem, 2000). The increase in demand changes travel behaviour of individuals (Nass et al., 2001). The following effects are likely to occur on the short term: Changes in the modal split, by reducing time and/or costs of road transport but not those of rail transport, changes in travelling distance and thus time, changes in choices for routes and changes in proportion of people travelling at certain time periods, such as peak periods (Downs, 2004; Noland & Lem, 2000). Some of these changes will inevitably lead to more emissions.

Overall, the materials seem to cause the largest amount of emissions (Hanson & Noland, 2015). Most of the discussed researches on these topics focus on how to reduce the emissions. The suggestions that come forward mostly bring extra costs and some of them are not necessarily feasible, but there are opportunities for certain cases to reduce emissions of the overall road construction and usage. These emission aspects are only a broad collection of all the emissions that road infrastructure might cause. The actual total emissions highly depend on what the researcher includes in the estimations.

2.6. Methods to capture spatial dynamics

There is a lack of knowledge and research on the effect of an improved road network on attributes such as health, education and employment as a whole dynamic system. This section discusses the different methods do capture these spatial dynamics.

2.6.1. Transport modelling

Although the world - including transport - is changing fast, we still face similar challenges as we did in the past: pollution, congestion, accidents and poor access (Ortúzar & Willumsen, 2011). Solutions such as connecting distant rural areas with markets, providing accessibility to basic needs, etc. have been put to practice in the developed world but are still needed in the developing world. The majority of nowadays transport models are established to solve pollution and congestion related problems. Still, some of these models can be used to tackle the discussed problems. This research aims to capture the dynamics of a changing (over time) road network and how this affects socio-economic factors through improved accessibility. According to Ortúzar & Willumsen (2011), accessibility is the interrelating factor between transport and land-use. A widely used approach to capture the interaction between transport improvements and social and economic processes is the land-use transport interaction (LUTI) (Wenban-Smith et al., 2009).

LUTI modelling LUTI modelling allows incorporating the interaction between land-use and transport, the demographic and economic developments at the national level and the behaviour and individual responses of citizens and firms (Acheampong & Silva, 2015; Schoemakers & van der Hoorn, 2004). The models have been designed to simulate the complex relationships between these elements. Traditionally, these models have been used to simulate the possible effects of the introduction of new policies and projects in existing systems and especially, those systems related to transport (Coppola et al., 2013; Foot, 2017). Therefore, LUTI models have been mostly used as complementary tools to transport models. Examples of LUTI models are TIGRIS XL (The Netherlands) and LonLUTI (London, UK).

The TIGRIS XL model is developed to address specific sectors. It is an integrated system of sub-models with the underlying assumption that the system is not in equilibrium at a certain moment in time. The system moves towards an equilibrium depending on time lags (Zondag et al., 2015). The land-use model is fully integrated with the Dutch National transport Model System (NMS). The five major components of the model are five markets: labour market, transport market, housing market, land market and real estate market. TIGRIS XL is mostly used to determine the effects of infrastructure concepts on land-use, to determine the effects of spatial planning on transportation and is solely used for policy development, not evaluation (van Nes, 2018).

The LonLUTI model was developed to provide the top strategic level of transport analysis supporting London's spatial planning work commissioned by Transport for London (TfL) (Wenban-Smith et al., 2009). As for the land-use component, the LonLUTI model includes a range of economic and social relationships as well as development of land and use of buildings. The transport component includes combining base date activity data (2001) with accessibility information from a conventional transport model. The LonLUTI is mostly suitable to assess the impact of a major transport scheme on land-use and land-use regulation policies (TfL, 2018).

Within LUTI modelling, there are several dynamics focused approaches. For instance the Urban Simulation and the System Dynamics Approach (Ortúzar & Willumsen, 2011). The Urban Simulation approach is highly focused on urban land-use and transport interactions. System Dynamics (SD) is a more general modelling method and is suitable for evaluation policies in dynamic systems. This meets the following requirements: estimating effects of a policy measure on a system - in particular a country and give insight in long term results and effects of a policy measure such as road infrastructure investment on a system or country. Therefore, this research uses SD as a modelling approach.

2.6.2. System Dynamics

System Dynamics is "a method to describe, model, simulate and analyze dynamically complex issues and/or systems in terms of the processes, information, organizational boundaries and strategies" (Pruyt, 2013). SD allows one to learn about modes of behaviour of a particular dynamic system and to design policies which improve performance (Forrester, 1997). The SD approach is ideal for analysing the behaviour of socio-technical systems that involve multiple and interacting dynamic processes and time-delays (Sterman, 2000). The fundamental principle of SD is that structure determines behaviour (Brailsford, 2008). The system dynamics approach has been applied to many different domains in scientific research. Many applications of system dynamics models are in the domain of health care and in specific health care policies in a specific country or region (Atkinson et al., 2015; Brailsford, 2008; Dangerfield, 1999; Royston et al., 1999). Another widely used application is energy consumption, energy policies and energy transitions (Chyong Chi et al., 2009; Ford, 1997; Qudrat-Ullah & Seong, 2010). A third domain to which system dynamics is applied regularly is supply chain modelling. Some researches focus on the uncertainty of the supply chain (Langroodi & Amiri, 2016), others on specific food supply chains (Georgiadis et al., 2005; Minegishi & Thiel, 2000) and some on capacity planning in supply chains (Vlachos et al., 2007). A smaller part of the supply chain modelling is the transportation area. Fields of application include transportation in supply chain management, highway maintenance, take-up of alternate fuel vehicles, airport infrastructure, airline business cycles and strategic policy (Shepherd, 2014). There are many claimed advantages of using SD as a modelling framework for solving transportation problems (Abbas & Bell, 1994). The list below gives a selection of these advantages:

1. SD provides a logical and systematic representation of complex large-scale, multi-scale and multi-layer systems, such as transportation systems.
2. In most research, forecasts such as land-use, socio-economic factors and demography are retrieved from separate modelling techniques. These are subsequently used as external inputs into transportation models, which results in inconsistencies and incompatibilities. This can lead to inaccuracies of results. SD models can provide a common framework to capture the holistic view of transportation systems and incorporate other related sectors in these systems.
3. SD modelling enables the dynamic behaviour of the transport system by modelling dynamic, causal feedback interactions of the structural components as well as by empirically based formulations. Results of conventional transport models are purely reached through empirically based formulations.
4. SD simulation provides insight into the dynamic nature of transport problems by showing short-term and long-term behaviour of a transport system. This allows for timely adjustments to be made and it can be of help by policy- and decision-making processes, which - as established before - are essential for most developing countries with limited expenditures.

Furthermore, SD allows for incorporating multiple and different geo-spatial scales, for instance national, regional and local within one model. This is called multi-scale modelling. It ensures that the model will remain small and uncomplicated, while processing large amounts of data. The multi-scale modelling in system dynamics has not been researched yet and incorporating that in this study would serve as a contribution to scientific research. However, there are some pitfalls and limitations of using SD modelling for transportation systems as well (Abbas & Bell, 1994). First of all, SD models are aggregate models intended to illustrate and analyse policy impacts. In order to provide more numerical, accurate output, SD model should be refined to enable describing systems more detailed. However, this research aims to capture the holistic view which requires aggregate and simplified models. Another limitation is that the main aim of SD models is to assist policy-makers in finding an optimum design policy. Finding this optimum in complex, heuristic systems can be difficult and time-consuming. The main aim of thesis is not necessarily to find the optimum design policy, but attempts to provide insights in the effects of road infrastructure investments on certain socio-economic factors of Namibian society.

2.7. Related Research

To capture the holistic perspective of the impact of an improved road network on socio-economic factors, a dynamic approach is needed. Extensive research is available on using dynamic models to apprehend these effects. Most SD models with a focus on transportation look at the interaction of economy, population, migration, infrastructure and land-use with transportation. The traditional way of modelling this interaction is land-use transport interaction models (LUTI). However, the two time scales of transportation versus land-use are divergent. Transport users can respond relatively easy to changes in price, time and policy. The land-use system has a long time-scale being dependent on physical structures such as buildings, existing transport infrastructure. "This time dependence between the systems makes it ideal for a system dynamics approach" (Shepherd, 2014). Fields of application include transportation in supply chain management, highway maintenance, take-up of alternate fuel vehicles, airport infrastructure, airline business cycles and strategic policy

(Shepherd, 2014). This research focuses mostly on strategic policy. Within this field, a great variety of research has been performed using SD of which most conduct a case study. Table 2.1 in the appendix shows different researches with the variables and the software used for each research. None of the researches focus on the effects of the physical expansion of the road network on a society in a developing country. Also, most of these researches focus on a city, so regional level. There is little research on a national scale on a more rural, low-densely populated level. A similar study to this research, which is still going on, with a case study on India has been done by Rawal et al. (2015). The author aims to analyse the impact of road transportation and developing plausible policy decisions for sustainable development in Kanyakumari District, India. The focus of this research is - so far - more on reducing vehicle movements and therefore pollution to contribute to sustainable development and is restricted to regional development of one specific region. The author concludes that his research is currently lacking the analysis and understanding of "the impact of road transportation system on other entities like industries, health-care, education, housing, agriculture, agricultural infrastructure, tourism etc., to have a holistic perspective for integrated regional development planning." (Rawal et al., 2015). This thesis partly fulfils that research gap, by investigating the impact of the road transportation system on entities like health care, education and tourism.

Study	Subject	Case study	Variables
Pfaffenbichler et al. (2010)	Transferability between cities	-	Congestion, capacity, car use,
Haghani et al. (2003a), Haghani et al. (2003b)	Impacts of highway capacity expansion and related changes in land-use	Montgomery County, MD - USA	Physical, socio-economic and policy
Shen et al. (2009)	Population growth and land-use policies	Hong Kong - China	Employment, housing, transport, urban land area
Haghshenas et al. (2015)	Transportation policies for sustainability covering various cities in the world	Isfahan - Iran	Pollution, energy consumption, land consumption, costs, safety, accessibility, variety
Wang et al. (2008)	Vehicle ownership in certain populations	Dalian - China	Population, vehicle ownership, congestion, pollution, GDP
Feng & Hsieh (2009)	Maximising transport diversity	Taipei - Taiwan	MRT trips and accessibility, policy measures
Pataki et al. (2009)	Transport and ecosystem of fossil fuel emissions	Salt Lake Valley, Utah - USA	Role of climate, urban expansion, urban form, transportation, urban forest
Han & Hayashi (2008)	China's intercity passenger transport	China	Passenger capacity, traffic network length, fuel consumption, gasoline price
Egilmez & Tatari (2012)	Strategies to reduce overall impact regarding sustainability	-	Population, GDP, wealth, vehicle stock, vehicle miles travelled, congestion, emissions, highway capacity, land-use
Piattelli et al. (2002)	Policy making in the control of goods transportation growth by possible alternative modes	Germany	Investment in infrastructure, subsidies, fuel costs and carbon taxes
Liu & Wall (2006)	Impacts of congestion pricing policy on transportation socio-economic system	-	Congestion pricing, demand and supply, congestion, travellers perceptions

Table 2.1: Research on transportation modelling with a system dynamics approach

2.8. Conclusion | Literature Review

This chapter aimed to find relationships between the road infrastructure and the different factors and relations between the factors themselves. The result of this is summarised as the answer on RQ3.. Furthermore, this chapter discussed how this research fits in the sustainable development goals and with that it confirms the societal contribution. Section 2.6 showed different methods to capture spatial dynamics and concludes that System Dynamics is the most suitable method to use in this research. The last section discusses related research in this field and concludes that most studies do not include the effects of the physical expansion of road infrastructure on a society in a developing country and that it is mostly focused on regional and urban areas solely. This study attempts to investigate the effects of an expanded road network on mostly rural areas from a national perspective on constituency level and with these insights it would fill this gap in literature.

RQ1: "What are the relations between road infrastructure, road safety, emissions, economic growth, education, health, employment and tourism based on literature?"

- **Economic growth**
  There is a bidirectional relation between road infrastructure and economic growth. This research looks at the broader consequences of transport capital; more specifically the socio-economic factors underlying the relationship. Since this study is on performed on a highly aggregated level, not all underlying mechanisms and factors can be taken into account and the relation between road infrastructure and economic growth remains highly aggregated as well. The influence of economic growth on transport infrastructure is not uniformly determined in research. The relation is dependent on both the context and the type of infrastructure. However, differences among researchers occur in terms of the existence of an influence of GDP on road infrastructure. Both relations can be seen as uncertain relations, which means that the relation is not able to be relied on, not known or not definite.
- **Accessibility**
  In general, a better or more extended road network increases the accessibility of an individual and of facilities. Accessibility in terms of a proper road network is considered to be a key component of - among other things - poverty reduction. This study includes the land-use, the transport and the individual component and it mostly uses the person-based measures. The list below shows how road infrastructure affects the socio-economic factors and how some of them relate to each other:
  - Roads and education: a better road network leads to a better accessibility of educational facilities. Topography is a powerful determinant of education participation. Also, better accessibility improves the quality of education, which contributes to the economic growth of a country.
  - Roads and health: an improved road network evidently leads to a better access to health care facilities and thus an improved health situation. A huge improvement could be made in the U5MR in developing countries by shortening distances to facilities. Higher life expectancy has a positive influence on the economic growth.
  - Roads and employment: road infrastructure influences employment both by direct employment through construction and maintenance and better accessibility to jobs. The impact of employment on economic growth remains ambiguous and is therefore not taken into account.
  - Roads and tourism: tourists value a reliable and safe transport infrastructure. An improved road network is found to enhance tourism in developing countries. Tourism is a direct driver of economic growth.
  - Education and employment: this relation is highly context dependent, but in general a positive influence of (improved quality of) education on employment is found. A case-study should point out if there is a relation and what the magnitude is.
  - Tourism and employment: this context dependent as well and different researchers conclude various things. The same goes for tourism and employment as education and employment.
  - Health and education: this is a bidirectional relation.

- **Road safety**
Road safety is a major issue with regards to road infrastructure, mainly in developing countries. Predictions are that the number of road crashes and the number of road traffic deaths will increase in the coming years. Road traffic injuries cost the governments between 1% and 3% of their gross national product on a yearly basis.

- **Emissions**
Road infrastructure (currently) inevitably leads to more emissions. Overall, the materials seem to cause the largest amount of emissions. Most of the discussed researches on these topics focus on how to reduce the emissions. The suggestions that come forward mostly bring extra costs and some of them are not necessarily feasible, but there are opportunities for certain cases to reduce emissions of the overall road construction and usage.

3
Namibia

This chapter aims to assess the existing conditions of Namibia to get a complete and comprehensive overview of the country. This chapter seeks to answer the first two research questions: "What is the socio-demographic status of Namibia and how does the current accessibility affect this?" and "What is the current transport infrastructure situation in Namibia?" and therefore the socio-economic and infrastructure functions of the system will be described. The subsequent sections provide an analysis in light of this research question. Section 3.1 delineates a general introduction to Namibia, discussing the reasons that Namibia is used as a case for this research. The section includes a description on their plans for development. The preceding section 3.2 elaborates on the socio-economic status of Namibia. The third section 3.3 elucidates on the present state of the transport infrastructure in Namibia. The main insights are summarised and the answers to the research questions are given in the chapter synthesis 3.4.

3.1. Introduction to Namibia

Namibia is a country in Southern Africa and is part of the Southern African Development Community (SADC). Namibia is classified by the United Nations as a developing country and an upper middle income country with a per capita GDP of US $4.415 (United Nations, 2017; 2018f). Today's development challenges emanate from a combination of factors including the country's recent colonial and apartheid past, demographic and geo-physical features and public policy choices (Levine et al., 2011). Namibia, formerly South West Africa, was colonised by Germany in 1884, but during World War I - 1915 - it came under South African martial law until Independence in 1990. Due to this colonisation over the years, many different ethnic groups inhabit Namibia nowadays. The population of 2 533 794 people(United Nations Department of Economic and Social Affairs, 2017) inhabit a country surface of 824 290 square kilometres (The World Bank, 2017b) which makes Namibia the second lowest population density in the world. This is mainly due to the fact that large parts of the country are too dry for human settlement. Namibia borders Angola and Zambia in the north, Botswana in the east and South Africa in the south and its western border is the Atlantic Ocean. Namibia has one of the highest levels of income inequality in the world (Akinwumi Ayodeji et al., 2017). A common way of measuring income inequality is the Gini coefficient, which ranges from 0 (complete equality) and 1 (complete inequality). The Gini coefficient in Namibia is 0,57 as of 2017, which is one of the highest in the world (Akinwumi Ayodeji et al., 2017). The Namibian economy is closely linked to the South African economy, with the Namibian dollar being pegged to 1:1 to the South African Rand. Section 3.2 discusses more characteristics of Namibia and its inhabitants.

Namibia as a case

There are several reasons why the country of Namibia is used as a case for this research.

1. Namibia is a country with large differences. There is a lot of inequality in terms of income and in parts of the country people live in huts without access to sanitary facilities whereas the bigger cities are quite developed and advanced in terms of road network and sometimes public transport (Anand & Segal, 2008). The existing transport system in Namibia is of relative good quality, especially the road infrastructure. The World Economic Forum (WEF) ranks the quality of Namibian roads 30th in the world, having the best roads of Africa (Roads Authority, 2018b; Schwab, 2017). This means that one can investigate the effects of the transport infrastructure and that there is still a lot of room for improvement.

2. The Namibian government is aware of present inequalities and other challenges currently present and therefore deployed a vision for 2030. In order to implement and achieve the objectives of this long term vision (Vision 2030), a National Development Plan is developed every four or five years. Currently, the Fifth National Development Plan (NDP5) is in operation together with the complementary Harambee Plan for Prosperity (HPP). Transport infrastructure is discussed in detail and the plans are ambitious. The reports show that the sector transport and logistics accounts for 3,6% of the total workforce and a 4,7% to the GDP (National Planning Commission, 2017). According to the development plan, "transport and logistics are essential for trade, industrialisation, socio-economic development and regional integration" and the sector has the potential "to enhance industrial development and contribute substantially to the GDP..." (National Planning Commission, 2017). The main ambition regarding transport and logistics is that "by 2022, Namibia has a sustainable transport system supporting a world-class logistics hub connecting SADC to international markets". More information on the NDP and the HPP and the role of transport and logistics in these plans can be found in this section and section 3.3.
3. Some of the effects that transport infrastructure influences other than economic growth, as discussed in the general introduction are highly applicable to Namibia. Namibia highly depend on tourism with a contribution to the GDP of N$ 4.682 billion (National Planning Commission, 2017). Besides, health, education and employment are important and challenging issues that Namibia is currently facing. Literature points out that an improved transport infrastructure will most probably be beneficial for these factors, hence looking into the exact effects that transport infrastructure will have is useful.
4. There is a lot of general data of Namibia, as the result of the Namibia Population and Housing Censuses that the National Statistics Agency (NSA) conducted in 1991, 2001 and 2011. This research uses data from the most recent census (Namibia Statistics Agency, 2011). For the purpose of this thesis, there is full access to this data. More information and explanation about these data will be given in 4.1.

On account of these reasons, Namibia is a very suitable country to investigate the effects of transport infrastructure effects on society and to apply the theoretical framework (figure 2.1) on.

NDP & HPP

Ever since its independence in 1990, Namibia is struggling with major issues such as one of the biggest income inequalities of the world, unemployment and health and education issues. To approach these issues the Vision 2030 was deployed and in order to implement this, a National Development Plan is developed every five years. Currently, the NPD5 is in operating together with the complementary HPP. Both plans are briefly discussed in the paragraphs below.

NDP The first National Development Plan (NDP) was carried out by the National Planning Commission (NPC) in 1995 and covered the period of 1995/1996 until 1999/2000. The main focus of this development plan was the diversification of the economy and the consolidation of the achievements realised during the initial five years of Independence (National Planning Commission, 2018). The current NDP5 runs from 2017/2018 - 2021/2022. The report is structured by four pillars: economic progression, social transformation, environmental sustainability and good governance. Furthermore, the NDP identifies five game changers that will move Namibia from a reactive, input-based economy towards a proactive, high performing economy. The game changers are (i) Increase investment in infrastructure development; (ii) Increase productivity in agriculture, especially for smallholder farmers; (iii) Invest in quality technical skills development; (iv) Improve value addition in natural resources; and (v) Achieve industrial development through Local Procurement.

HPP The Harambee Plan for Prosperity (HPP) has been developed in 2016 to complement the National Development Plans and the Vision 2030. The HPP has a bigger focus on presenting practical realisations on the plans presented in NDP. The HPP report consists of five pillars: effective governance, economic advancement, social progression, infrastructure development and international relations and cooperation.

3.2. Sociodemographic status of Namibia

This section aims to answer the second research question: 'What is the socio-demographic status of Namibia and how does the current accessibility affect this?' The first subsection discusses the population of Namibia, which includes ethnicity, education, employment and health. The second subsection focuses on Namibia's economy by discussing several value-adding industries.

3.2.1. Population

Namibia's nowadays consist of 2.533.794 people [1]. Figure 3.1 shows the population growth from 1921 until 2012.

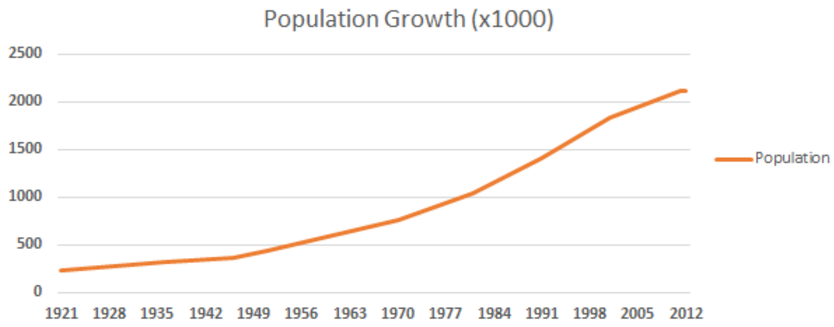


Figure 3.1: Population Growth of Namibia

The population has grown extensively and projections are - according to Namibia Statistics Agency (2014) - that "the national population is expected to increase from 2,28 million to 2,96 million i.e. an increase of 30 percent between year 2015 and 2030. Urban areas are expected to grow rapidly, in contrast to rural areas, which are projected to shrink gradually."

Table 3.1: Population of Namibia distributed over age and gender (Census data 2011)

Age group	Female	Male
0-4	142.821	141.877
5 - 9	120.470	118.980
10 - 14	123.980	122.014
15 - 19	121.451	117.412
20 - 24	109.321	106.260
25 - 29	90.629	86.609
30 - 34	75.797	73.293
35 - 39	64.031	60.864
40 - 44	51.105	46.926
45 - 49	43.119	37.441
50 - 54	34.097	27.404
55 - 59	26.368	21.505
60 - 64	22.404	18.409
65 - 69	17.987	13.109
70 - 74	13.831	10.256
75 - 79	10.234	7.012
80 - 84	9.059	5.274
85 - 89	6.180	3.126
90 - 94	4.430	2.378

Table 3.2: Percentage share of population census year and area (Census data 2011)

Area	Percentage (%)		
	1991	2001	2011
Namibia	100,0	100,0	100,0
Urban	27,1	33,0	42,8
Rural	72,9	67,0	57,3
Caprivi	6,4	4,4	4,3
Erongo	3,9	5,9	7,1
Hardap	4,7	3,7	3,8
Karas	4,3	3,8	3,7
Kavango	8,3	11,1	10,6
Khomas	11,9	13,7	16,2
Kunene	4,5	3,8	4,1
Ohangwena	12,7	12,5	11,6
Omaheke	3,7	3,7	3,4
Omusati	13,5	12,5	11,5
Oshana	9,6	8,9	8,4
Oshikoto	9,1	8,8	8,6
Otjozondjupa	7,3	7,4	6,8

The Namibian government is conducting Populating and Housing Census every 10 years since its independence in 1990. The Censuses were held in 1991, 2001 and 2011. The data is not very recent but since it

[1] In 'World Population Prospects: The 2017 Revision' by United Nations Department of Economic and Social Affairs (2017)

is the most complete and accurate data, this will be used for the model. The population in 2011 consisted of 2.107.463 people. Table 3.1 below shows the distribution of this number of people over age and gender. The average age in Namibia is 25 (based on the same census data). This means that the population is relatively young, which is most probably the result of an increasing birth rate and a relatively low life expectancy of 57 years on average. To give some indication, the average age in The Netherlands is 42 and the average life expectancy is 82 year (WHO, 2016). Table 3.2 shows the percentage of people living in each area, over time of the three censuses. The region division of Namibia has recently changed, but because of the census data, this research assumes the region division as of 2011. Figure 3.2 shows a map of the population density of Namibia per region. The population is spread very unevenly across the country. Most people live in the northern re-

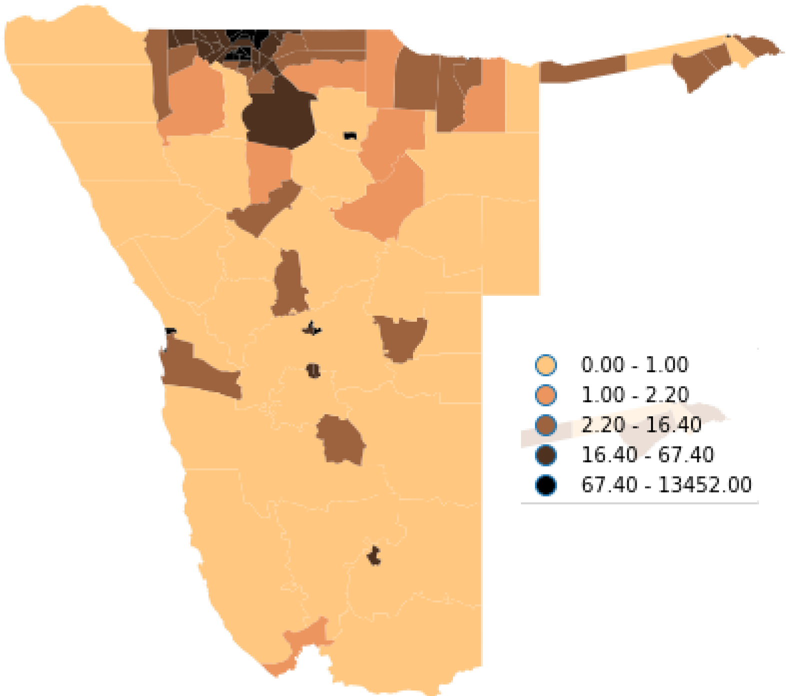


Figure 3.2: Population density by constituency in people/km^2

gions Oshana and Ohangwena where after in Khomas and Omusati. The capital city Windhoek is located in the region Khomas and besides that, most people tend to live in the north of Namibia, touching the borders of Angola. The right hand table 3.2 shows an increase of urbanisation from 1991 to 2011, partially caused by the increase in population in Khomas (region of Windhoek). Differences between larger settlements with higher population densities and deserted areas where few people live are huge. Some constituencies are underdeveloped with poor access to health, education and work. For instance Nehale lya Mpingana where inhabitants express their dissatisfaction about access to basic services. The constituency is accessible solely via a sandy road only 4x4 vehicles can travel on (The Namibian, 2017). Large parts of the country are too dry for human settlement, which explains the division of inhabitants over certain regions. Namibia has been growing steadily from the first official measurements in 1921 with 228 916 inhabitants to 2 113 077 inhabitants in 2011. This population is still increasing and expectations are that it will continue to grow in the future.

Ethnicity Originally, Namibia was inhabited by the Ovambo and Kavango, who lived mostly up north towards Angolan borders. During the 17th century, the Herero, a pastoral, nomadic people keeping cattle moved into from Namibia. They came from the east African lakes. There is still a remainder of these people, the Himba people around the border with Angola. A remainder of Namibia's colonisation past can be seen in its current population diversity. The major distinction is made as follows: 87.5% is black, 6% is white and 6.5% is mixed (CIA, 2018). A more specified distinction in ethnicity is spoken language. Table 3.3 illustrates all languages spoken in Namibia in percentages of the total population. The speaking of these languages highly differs per region and most languages mentioned in table 3.3 represent a certain region (such as Caprivi and Kavango).

Table 3.3: Languages spoken in Namibia (Census data 2011)

Main language spoken	Percentage (%)
Namibia	100,0
San languages	0,8
Caprivi languages	4,8
Otjiherero languages	8,6
Kavango languages	8,5
Nama/Damara	11,3
Oshiwambo languages	48,9
Setswana	0,3
Afrikaans	10,4
German	0,9
English	3,4
Other European languages	0,7
Other African languages	1,3
Asian languages	0,1
Don't know	0,0

Education The education system in Namibia is divided in three levels: primary, secondary and tertiary education. Primary education is roundabout from the age of 7 (grade 1) until the age of 13 (grade 7) and secondary education from the age of 14 (grade 8) until the age of 18 (grade 12). Namibia has 1,698 primary and secondary schools of which the majority is governmental. The enrolment rate is quite high at the age of 8 (88,9%, Census 2011), but starts dropping at the age of 12 to a rate of 60% by the age of 18 and 34,3% by the age of 20. This indicates that people do not regularly commit to tertiary education. The options for education after secondary school are either university (tertiary education) or Technical, Vocational Education and Training (TVET). Namibia has three universities: Namibia University of Science and Technology (formerly the Polytechnic of Namibia) in Windhoek, University of Namibia (UNAM) in Windhoek with extra 'colleges of education' in Katima Mulilo (Caprivi/Zambezi region), Rundu and Ongwediva (Oshana region) and the International University of Management in Windhoek. All three universities are English universities and since English education in some rural areas is not sufficient, not everyone Namibian can attend these universities. The TVET attempts to make institutional and capacity building enhance the productivity of labour and addresses youth unemployment through an effective and sustainable system of skill formation (Ministry of Education, 2005).

The NDP 5 does conclude that currently there is a "lack of access to quality education and training opportunities", which makes it much harder for individuals to acquire knowledge and skills valued by the labour market through which they can lift themselves out of poverty. It is not specified what exactly is meant by access, but in the same NDP it is concluded that children in urban areas were more likely to receive ECD services than children in rural areas, which can probably mostly be explained by the difference in infrastructure.

Health Improving health care and the accessibility to health care facilities for everyone is high on the agenda of the Namibian government (National Planning Commission, 2017). Namibia has improved a lot with regards to health over the years, indicated by: (i) a significant reduce in maternal and neonatal mortality, (ii) a decline of infant and under-five mortality, (iii) a reduce in HIV/AIDS contaminated pregnant women from 22% (2002) to 16.9% (2014), (iv) all health facilities offering antenatal services now which results in 87% of all births occurring in health facilities and 88% is attended to by skilled birth attendants and (v) the immunisation coverage being improved substantially from 2012-2017 (National Planning Commission, 2017). Remaining challenges with regards to health are (i) eliminating communicable diseases spread by cross-border movements, (i) increase the limited availability of human resources in rural areas for mental health, (iii) increase the amount of health research in the country, (iv) more and better availability of (essential) drugs, (v) find solutions for the double burden of under-nutrition and overweight or obesity and (vi) find ways of proper maintenance of medical equipment (National Planning Commission, 2017). One of the determinants of the poor health that some people are in, is the lack of sanitary facilities in some areas. The HPP addresses this by setting a target to construct 30 000 rural toilets in the Harambee period. In table 3.4 the percentages of people having access to which type of toilet can be seen. The percentages are averages of the total population, originally measured per region. The differences per region per type of toilet accessibility are quite big. Based on this information and data, health and the urge of the improvement of health is considered to be an

Table 3.4: Percentage of total population (average over all regions) with access to different types of toilet facilities (Census data 2011)

Type of toilet accessibility	Percentage (%)
Private flush connected to sewer	18,28
Shared flush connected to sewer	6,32
Private flush connected to septic/cesspool	1,98
Shared flush connected to septic/cesspool	1,11
Pit latrine with ventilation pipe	4,70
Covered pit latrine without ventilation pipe	3,82
Uncovered pit latrine without ventilation pipe	2,12
Bucket toilet	2,29
No toilet facility	57,92
Other	0,89

important factor for Namibia. Therefore, health is included in the model and the preceding research. One of the challenges of the Social protection system the NDP 5 identifies is the lack of access to energy, water and other basic infrastructure. Other basic infrastructure probably partly consists of transport infrastructure. The report concludes that "the poor in rural areas are often lacking the most basic features of modern life without which it is difficult to remain in good health, develop complex skills and create home-based businesses." (National Planning Commission, 2017). However, it remains unclear if the Namibian government sees transport infrastructure and accessibility as a direct influence on the health situation in Namibia.

Employment 36,9% of the total population in Namibia is unemployed (Census data 2011). Unemployment is a big issue in Namibia, and unemployment rates are not dropping even though Independence seemed promising in terms of creating jobs. The country performs worse in terms of unemployment than fellow and surrounding African countries. The government is trying to look for ways to decrease the unemployment rate (published in NDP and HPP). The main occupation of both female and male inhabitants is skilled agricultural and fishery workers (respectively 29,3% and 24,1%) and the main job for both is private employee. One can conclude that the government is looking for creating job opportunities at all times to reduce the unemployment rate. This is considered a very important factor for Namibia. The NDP5 does not extensively discuss reasons for the high unemployment rate, but they do measure a higher rural unemployment rate then the urban. This is mostly caused by the economic activity in rural areas being low. An improved road network can make the accessibility towards these economic activities better.

Land With 2 533 794 inhabitants on a country surface of 824 290, Namibia is the second lowest densely populated country in the world. A major reason for this is the type of landscapes within the country, which make parts of the country uninhabitable. Figure 3.3 shows an overview of the land cover of Namibia, where land cover refers to "the vegetative community characterising the landscape." Except from Swakopmund, Walvis Bay and Lüderitz, the Southern, Central and North Namib Desert are barely inhabited. A major pivotal issue to the socio-economic development in Namibia is land reform. The major part of the privately owned land is owned by white, German farmers and a part of the remainder population attempts to get (some of the) land back.The government started the land reform program after its dependence in 1990. Nowadays, they make use of the willing buyer-willing seller system to buy land from private farm owners who owned the land before independence. This land is sold at market prices. The Ministry of Land Reform targets to acquire 5 million hectares by 2020. So far, it has acquired 64%, or 3,2 million hectares in total (Ministry of Land Reform, 2018).

3.2.2. Economy

Namibia's current GDP is 13 245 billion US dollars (The World Bank, 2017b). Throughout the NDP4 (2012-2017), Namibia enjoyed an average economic growth of 4,6% per year (National Planning Commission, 2017). From 2013 to 2016 Namibia experienced a severe drought, which hit rock bottom in 2016. This reduced the average GDP growth - it could have been higher than 5% if there would not have been drought problems.

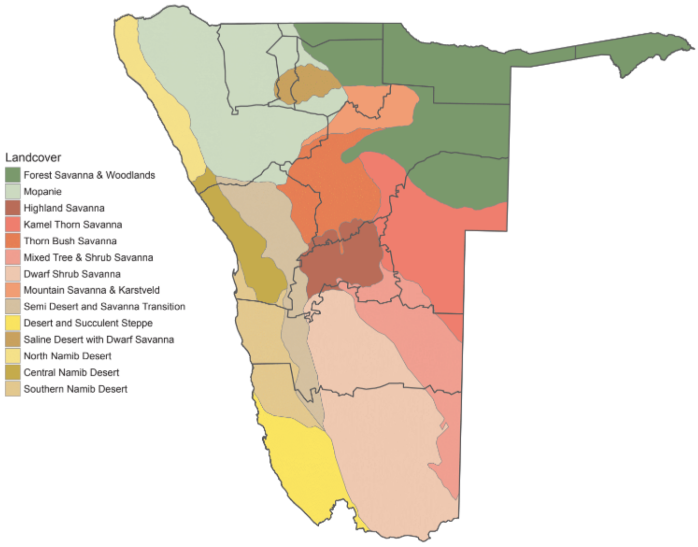


Figure 3.3: Landcover Namibia, source: Namibia Statistics Agency (2013a)

Several significant contributing sectors to the GDP are discussed in the paragraphs below. These sectors are designated to 'Value-added Industrialization' in the NDP5.

Agriculture This sector contributes 3,8% to the GDP of Namibia, but it supports 70% of the Namibian population and employs about a third of the working force (National Planning Commission, 2017). Continuous drought and outbreaks of animal diseases affect this sector majorly. Poverty is a major factor limiting access to food and access to food in Namibian is affected by reliance on market purchases for food. This, combined with the heavy reliance on food imports, makes Namibia vulnerable to high food prices. This is a large dynamic system on its own and given time limitations, agriculture is not taken into account in the remainder of this research.

MSME One of the big contributions to the GDP is made by the Micro, Small and Medium Enterprises (MSME) sector (12%). This sector employs around 129 000 people. MSME consists of all kinds of enterprises with different services and therefore this sector cannot be taken into account in the model of this research.

Manufacturing The manufacturing sector accounts for 11% of the total GDP in Namibia. According to the NDP5, the contribution of this sector should be greater than 11% and the three critical factors to the structural transformation of the manufacturing sector are diversification of the economy, sophistication of exports (value addition) and good governance that protects a sound investment climate and business environment (National Planning Commission, 2017). This sector has similarities with the MSME sector with regards to their size and diversity and therefore this sector will also be left out of the model.

Mining The mining sector contributes 12% to the GDP Namibia's mineral resources include diamonds, copper, uranium, lead, zinc, gold and semi-precious stones. The sector provides critical upstream, downstream and side-stream linkages for the Namibian economy such as transport services, power, water, skills, logistics and communications (National Planning Commission, 2017).

Tourism Namibia depends on tourism with a contribution to the GDP of N$ 4,682 billion and has a growing global reputation as a premier destination for eco-tourism. Tourists mostly visit Namibia for its flora and fauna, which can be negatively affected by emissions. Hence, keeping emissions low is of great relevance for the tourism industry, which is important contributor to the growth of the country's economy (National Planning Commission, 2017). This is confirmed by the Tourism Satellite Account Ministry of Environment and Tourism (2015), whose report indicates that the tourism industry *directly* contributes for 3,5% to the GDP and has 44.729 jobs representing 6,5% of total employment. Indirectly this is 10,2% and 14,5% respectively. Road infrastructure is, according to Millennium Challenge Account Namibia (2013), the most mentioned improvement in a survey for tourists in Namibia is the infrastructure. This implies that investing in transport infrastructure in Namibia will most likely enhance tourism and therefore generate economic growth. As came forward from literature research, tourism is directly positively influenced by an improved road network. Tourism is included in the model as conceptualised in chapter 6.

3.2.3. Infrastructure

Infrastructure compromises water, energy, ICT and transport and logistics.

Water Due to Namibia's arid climate coupled with high evaporation rates, it is the driest country in sub-Saharan Africa. This has great impact on water availability and reliability. With highly variable and unpredictable rainy seasons, water scarcity continues to be a serious problem and constraint in achieving the economic, environmental and social development objectives as formulated in the NDPs. Predictions are that water demand will increase in the coming 10 years. Irrigation accounts for 60% of the total water consumption (National Planning Commission, 2017).

Energy Only 24% of inhabitants in rural households have access to electricity. The electricity grid mainly reaches to urban areas and it is difficult and costly to install electricity supply in rural areas due to the low densely population and difficult landscapes. Namibia is highly dependent on neighbouring countries in terms of electricity, as 63% of Namibia's electricity is imported.

ICT This infrastructure does not cover the whole country. As of 2015, 25% of schools had access to broadband infrastructure and only 13% of health facilities. The country plans on increasing the ICT infrastructure to become a knowledge-based economy.

Transport and logistics This is the point of focus in this research, hence this physical infrastructure will be extensively discussed in the next section 3.3. The rest of the infrastructures will not be used in the remainder of this research.

3.3. Transport and logistics in Namibia

This research focuses the effects transport infrastructure investments on factors such as health, tourism and education which are underlying on economic growth. This section discusses the current transport infrastructure situation in Namibia, which includes roads, rail, ports and airports. The governmental party responsible for transport infrastructure is the Ministry of Works and Transport (MoWT). Their vision is to be "the lead contributor to Namibia's socio-economic development and growth through the provision of world-class infrastructure and services" (Ministry of Works and Transport, 2018). This section aims to answer the third research question: 'What is the current transport infrastructure situation in Namibia?' The first subsection discusses the numbers and plans on transport and logistics in the NDP5 and the HPP. The remainder subsections elaborate on the four transport infrastructures: road, rail, ports and airports. Figure 3.4 shows the transportation assets owned by households divided over rural and urban areas. The most outstanding aspect is the difference in car and motorbike ownership and the animal drawn cart ownership in rural and urban areas.

Transport and logistics in NDP 5 & HPP

Information about and plans on transport infrastructure can be found in the economic progression pillar and can be summarised as follows. The sector transport and logistics accounts for 3,6% of the total workforce and a 4,7% to the GDP (National Planning Commission, 2017). In the NDP5, a section within 'Structural Transformation through Value added Industrialization' as part of the economic progression is dedicated to the transport and logistics current situations and the goals for the future. According to the development plan, "transport and logistics are essential for trade, industrialisation, socio-economic development and regional integration" and the sector has the potential "to enhance industrial development and contribute substantially to the GDP..." (National Planning Commission, 2017). The main ambition regarding transport and logistics is that "by 2022, Namibia has a sustainable transport system supporting a world-class logistics hub connecting SADC to international markets". Improvement of the transport and logistics sector is needed for the other targets in NDP5: "a functional and efficient transport and logistics sector is the backbone for the realisation NDP5 targets in agriculture, mining, manufacturing, fisheries, rural and urban development

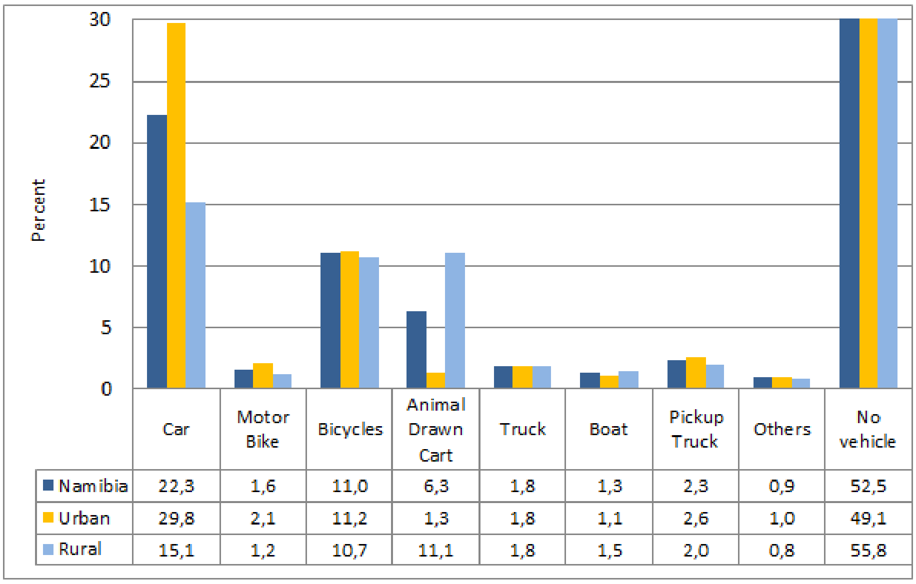


Figure 3.4: Percentage distribution of households owning selected transportation assets by region (Census data 2011)

and tourism. It is also a critical factor in promoting environmental sustainability." The HPP concludes that "in view of Namibia's ambition of becoming a logistics and distribution hub by 2030, significant investment outlays will have to be made for all four modes of transport infrastructure, namely road, rail, maritime and aviation" (Government of the Republic of Namibia, 2016). The desired goals and outcomes of the Harambee on transport are as follows:

- Completion of the deepening and expansion of the Port of Walvis Bay to be able to handle a minimum of one Million TEUs;
- The extension of bitumen roads by 526 kilometres, including the selective introduction of dual carriage ways;
- Upgrade of the national rail infrastructure by 612 kilometre to SADC standard;
- Ensure air safety standards.

One can conclude that there is a high focus and ambition on transport and logistics in the current NDP and HPP.

Road infrastructure in Namibia

The road network nowadays consists of 46 498,34 km. Figure 3.5 shows the road network on a map. Different colours indicate different types of roads. Most of the roads consist of gravel (25 603,84 km). One can see that some parts of the country remain without any road infrastructure. These are mostly uninhabited parts such as desert. Table 3.5 below shows the changes in the road network over 2012-2016. The table shows little changes in those years, both in terms of total length of the road network as the division of type of road. The responsible party of the roads in Namibia is the Roads Authority (RA). The RA constructs and maintains Namibia's roads and therefore plays a pivotal role towards road safety in Namibia. According to the RA, "the growth of the road infrastructure and the expansion of the road network have contributed immensely to

Table 3.5: Road length and material from 2012-2016

Year	Total [km]	Bitumen	Gravel	Earth	Salt	Otherwise
2012-2013	45645	14,60%	56,60%	25,10%	0,60%	3,30%
2013-2014	46378	15,45%	55,89%	24,88%	0,66%	3,12%
2014-2015	46378	15,45%	55,89%	24,88%	0,66%	3,12%
2015-2016	48328	15,07%	52,98%	26,95%	0%	4,37%

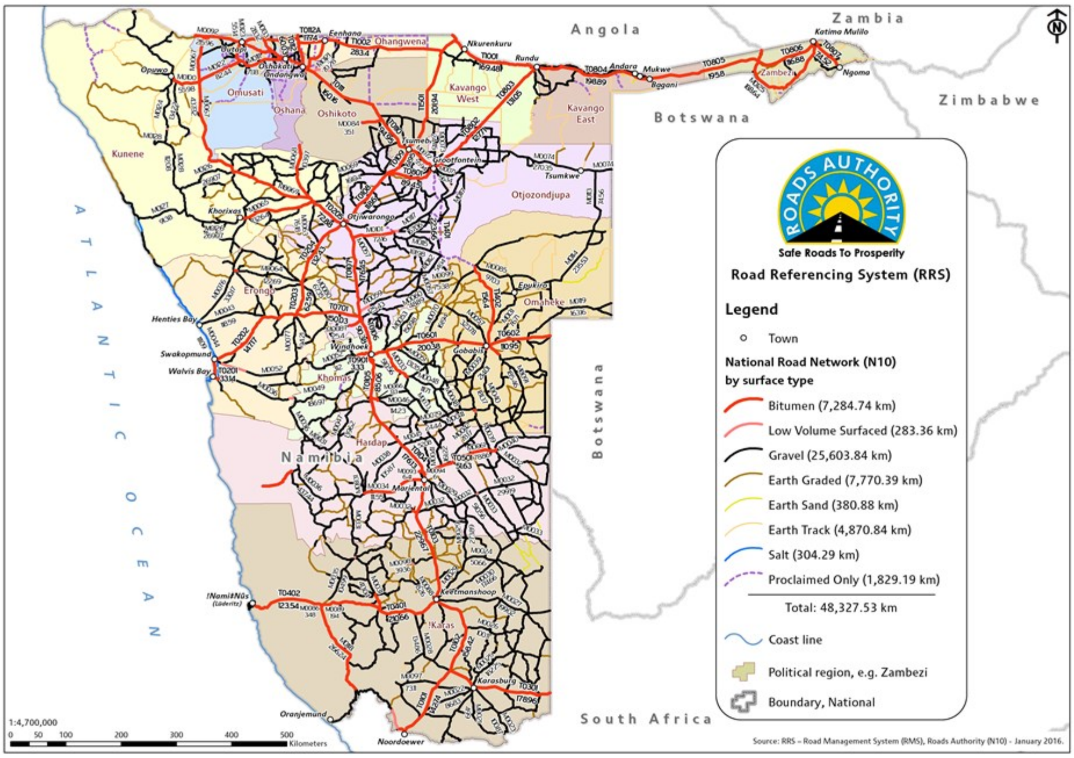


Figure 3.5: Namibian road network 2016 (Roads Authority, 2016)

the economic development of Namibia and the SADC sub-region as a whole" (Roads Authority, 2018a). Another party involved in the Namibian road sector is the Road Fund Administration (RFA), which manages the Namibian Road User Charging System (RUCS) and the Road Fund. The RUCS is a system that came into force in 1999 aims to provide for independent regulation or road funding by economically recovering the full cost of roads expenditure from road users in an equitable manner (Republic of Namibia, 1999). Users have to pay the following: fuel levies, vehicle registration and annual licensing fees, cross border charges, mass distance charges and abnormal load fees.

The RA faces several challenges with regards to the existing road network, such as overload prosecution, decriminalisation of overloading offences and the weighbridge management and operations. The biggest challenge for the road sector in general is the road safety. Many lives are taken by different kinds of accidents every year: within seven months of 2018 276 people died in road accidents (Cloete, 2018). According to the Namibian Statistics Agency (2015) (NSA), road accidents are one of the major causes of deaths in Namibia. Table 3.6 shows an overview of the fatalities and injuries due to road crashes from 2010 - 2015. Years 2010-

Table 3.6: Fatalities and injuries due to road crashes (Amweelo, 2016)

Year	**2010**	**2011**	**2012**	**2013**	**2014**	**2015**	**Average increase**
Fatalities	539	492	561	633	676	705	
Difference fatalities	-	*-9%*	*14%*	*13%*	*7%*	*4%*	*5,84%*
Injuries	5125	5659	5652	5845	6918	7371	
Difference injuries	-	*10%*	*0%*	*3%*	*18%*	*7%*	*7,72%*

2015 show an increase in both fatalities and injuries. Road crashes cost the sector N$1.3 billion every year (Namibian Broadcasting Corporation, 2017). The cost of road trauma including fatalities and serious injuries is estimated to equal approximately 3% of GDP per annum (NRSC, 2015). This is in line with the conclusion drawn in chapter 2.4, which said that injuries cost the government between 1% adn 3% of their GDP. Road safety is dependent on many different factors of which the material of the road is one. On bitumen roads, Safety can be either reduced because of higher possible speeds and hence higher risk of accidents or increased by a better condition of the road thus a lower chance of accidents (Figueroa et al., 2013). Hence, it is difficult to predict the exact effect of better and more infrastructure on safety. Since road accidents are such an issue in Namibia, investing in road infrastructure should be accompanied by investing in road safety. Forsyth (2016) writes in his report: “However, endemic failure among certain road users to comply with the provisions of the Regulations combined with poor enforcement measures mean that a great deal more can be done to improve the safety of Namibian roads”.

The numbers indicate that the road safety of Namibian roads needs to improve drastically. Several initiatives and organisations are working on increasing the safety. The Legal Assistance Centre (LAC) published the "Proposals for enhancing road safety in Namibia" in which they suggest several measures to increase road safety: demerit system as penalty for road safety violations, seat belts, speed limits and penalties for speeding, use of lights at all times, stricter penalties for drunk driving and use of cellphones, fines for disobeying traffic rules, penalties for fake licenses, the use of child restraints, the road-worthiness of vehicles and infrastructural planning (Forsyth, 2016). The RA mainly attempts to increase safety through consistent maintenance, fencing off road reserves and getting the road-worthiness of vehicles and the competency of drivers skills to international standards by upgrading the Vehicle and Driver Testing Centre and opening a Registering Authority for vehicle registration and licensing services (National Planning Commission, 2017). Furthermore, they will invest N$19 billion in road upgrades and new roads in the coming five years (Graig, 2018). The Harambee specifically mentions which road upgrades will be done for both safety and better accessibility. The upgrades include either dual carriage or bitumen standards (Government of the Republic of Namibia, 2016).

Rail infrastructure in Namibia

The rail network in Namibia consisted of 2687 kilometres as of 2011. This is the most recent official update on the rail network. The map in figure 3.6 illustrates the network on a map. Both the rails and the trains are exploited by TransNamib Holdings; a company wholly owned by the Namibian government. The current rail network is mostly used to transport freight.

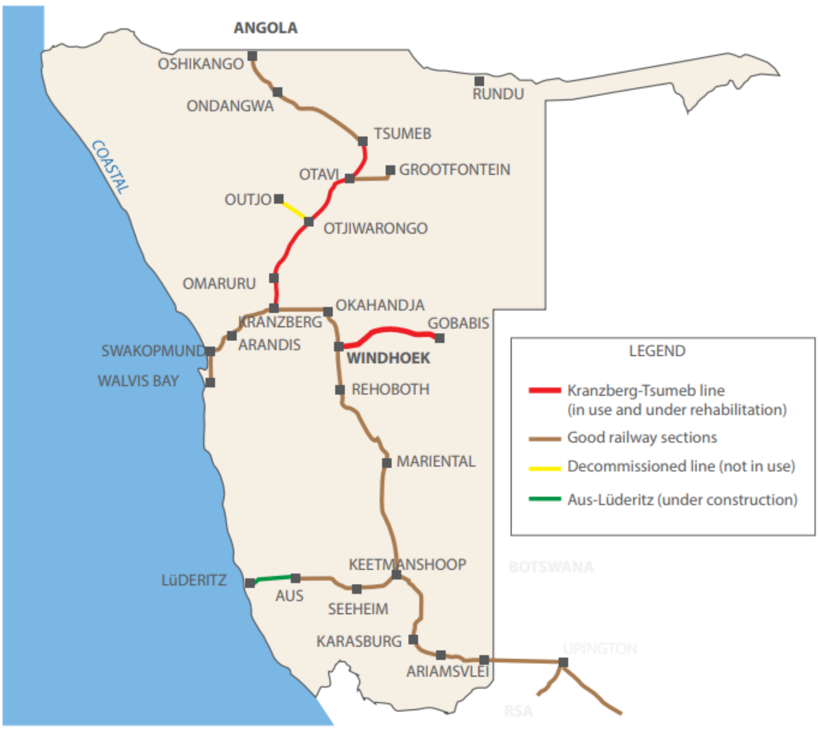


Figure 3.6: Rail Network in Namibia (TransNamib Holdings Ltd., 2011)

Table 3.7 shows the expected and real numbers on some indicators. All indicators tend to perform worse than expected; all actual outcomes are lower than expected numbers. There is no unambiguously cause for this, but several annual reports of the TransNamib Holding and the National Development Plans highlight a few issues and challenges in the current rail transport.

Table 3.7: The expected and turn-out performance on some indicators of the rail network in Namibia (adjusted table from (National Planning Commission, 2012)

Indicator	NDP3 target	Out-turn
Design of Non-motorised Transport Policy	1	0
Average freight transported annually by rail (t)	3 million	2,15 million
Average number of passengers transported annually (rail)	300 000	6800
Average wagon turnaround time (days)	5	8,2
Rail coverage (km)	3000	2488
Average locomotive availability (%)	95	69,5

- There is a history of derailments with severe consequences. They firstly decrease the safety, which most likely causes a lower attractiveness of the rail transport mode for passengers. Secondly they caused high losses for TransNamib Holdings (Poolman, 2012; TransNamib Holdings Ltd., 2013).
- Only 1,203 km of the total rail network of 2,626 km can carry the standard 18.5-t axle load, whilst the remaining lines are limited to 16.5 t or even only 13.5 t (National Planning Commission, 2012)
- Accidents involving motorists and pedestrians, especially at level crossings(TransNamib Holdings Ltd., 2011)

The following rail network upgrades are planned according to the Harambee (Government of the Republic of Namibia, 2016):

- Upgrading of the rail network from Walvis Bay to Tsumeb, to be fully completed by 2020.
- The upgrade of the Sandverhaar-Buchholzbrunn [40 kilometers].
- The construction of sand tunnels on the Aus-Luderitz railway.
- The introduction of a commuter train service between Windhoek Central and Katutura and other suburbs.
- The introduction of commuter train services between Windhoek and Rehoboth.
- The introduction of commuter train services between Windhoek and Okahandja, Windhoek to International Airport

Airports in Namibia

Namibia has eight commercial airports: Hosea Kutako (Windhoek international), Eros (Windhoek domestic), Walvis Bay, Luderitz, Keetmanshoop, Ondangwa, Rundu and Katima Mulilo. Windhoek international and Walvis Bay airport are operating both international flights and domestic flights. The other airports all operate domestic flights only. The following upgrades with regards to airports infrastructure are planned for the coming years according to the Harambee (Government of the Republic of Namibia, 2016):

- Upgrade of the Eros airport runway and terminal by June 2017.
- Upgrade of the Mpacha airport runway by end 2018.
- Upgrade of the Hosea Kutako International airport runway and terminal.

Ports in Namibia

Namibia has two main ports: Walvis Bay (largest commercial port, is supposed to become the logistics hub) and Lüderitz. Namibia is an important hub to serve the landlocked countries in their hinterland: Zambia, Zimbabwe and Botswana. Those three countries have their own dry ports in the port of Walvis Bay. As the NDP5 shows, Namibia is supposed to become a logistics hub for Southern Africa by 2022. One of the strategies to achieve this, is to expand the capacity of Walvis Bay. The purpose of the project is to double the existing design capacity of the port of Walvis Bay to 500,000 Twenty-foot Equivalent Units annual handling capacity by expanding the quay wall size, dredging the approach channel and upgrading the handling equipment (National Planning Commission, 2017). The existing container terminal at the Port of Walvis Bay has an approximate throughput capacity between 350,000 and 400,000 TEUs per year (Namport, 2016). The latest expectation is that the expansion of Walvis Bay Port is finished in June 2019 (Namport, 2018).

New initiatives

There are some initiatives trying to make transportation in Namibia more sustainable. The first one is the "Move Windhoek" initiative of the Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) GmbH which started in 2014. This initiative aims to help "decision-makers in the transport sector to develop an affordable, accessible, attractive and efficient public and non-motorised transport system for the next 20 years" (SUTP, 2018). The project attempts to improve the bus system in Windhoek and tries to encourage people to travel by bus or bike. Move Windhoek does not only address emission issues, it also reduces the spending of urban poor who spend 25% of their income on their mobility needs. The project ended in 2016 and 26 modern busses are operating now on a new route in Windhoek (GIZ, 2016). However, no reports on the actual outcomes of the project has been published yet. Therefore, it is hard to gauge if the project improved the addressed issues.

Conclusion transport and logistics Namibia

This section 3.3 aimed to answer the third research question: 'What is the current transport infrastructure situation in Namibia?' The full answer is given in the subsections above, but in summary it can be said that Namibia's current transport infrastructure is relatively good and extended. The most advanced transport infrastructure is the road infrastructure, where the rail infrastructure needs improvement and extension to make it a more attractive modality for both passengers and freight. Different (some independent) parties are responsible for each modality. Also, there are several initiatives trying to encourage the use of bicycles and more public transport in order to reduce emissions and reduce the amount of accidents. However, no actual numbers on these projects have been published yet. Although there are attempts to improve the current transport situation in terms of safety, social and economic problems and sustainability, reality is that the road sector will keep on investing in roads in the near future (Government of the Republic of Namibia, 2016; National Planning Commission, 2017). The plans in the NDP and the Harambee on becoming the logistics hub of the SADC by 2022 are clear and the government will act upon this ambition. The RA decided to invest a total amount of N$19 billion in the coming five years, where funding partly has to come from the Namibian government, part is funded by the RUSC and a loan will be requested (Graig, 2018). According to the RA, there is a positive effect of the growth of the road infrastructure and the expansion of the road network on the economic development of Namibia and the SADC sub-region as a whole. Research on the productivity of transport infrastructure investment by Melo et al. (2013) confirms that estimates of the productivity effect of transport infrastructure are higher for roads compared to other modes of transport. There is no specification of this effect with underlying factors such as health, education, etc. It seems that the Namibian government is not currently aware of the exact effects of improving road infrastructure and of the trade-offs between positive and negative aspects the policy-makers make when deciding to invest in road infrastructure. In order to possibly change the focus on road transport towards a more sustainable transport infrastructure and transport behaviour, awareness of and insights in the trade-offs between the effects is needed. Policy-makers can make substantiated decisions when having all information. Therefore, this thesis will focus on the road infrastructure in Namibia only.

An important note is that whilst making the decision to focus on road infrastructure only, the road safety aspect needs to be taken into account. It is not feasible for this short time-period to predict the exact effect of better and more roads on safety and the effect of the material of the roads on safety and therefore this effect will not be included in the model of this research. However, investing in road infrastructure should be accompanied by investing in road safety as well.

3.4. Conclusion | Namibia

This section aimed to answer the second and third research question, which is summarised below.

RQ2: "What is the socio-demographic status of Namibia and how does the current road infrastructure affect this?"

The full answer to this question can be found in section 3.2. Below is a summarised,short overview of the findings of this section:

- **Population:** The population has grown from 228.910 inhabitants in 1921 to 2.113.077 in 2011. Projections are that the population will continue growing to a size of 2.960.000 in 2030. Inhabitants of Namibia are have a variety of ethnicity and speak all different sorts of languages.
  - The education rates are high in primary school but start to get lower in secondary school. The NDP acknowledges that there is a lack of access to quality education and training opportunities and better accessibility by an improved road network might take a bit of this lack of access.
  - Health care has majorly improved over the past years, but there is still room for improvement. Health is not directly related to accessibility by the Namibian government, but they do conclude that poor people in rural areas are often lacking most basic features which makes it difficult to remain in good health. This could be an indicator of accessibility influencing the health level in Namibia.
  - There is a high unemployment rate in Namibia, especially among youth. This rate is higher in rural areas and this might indicate that a better accessibility to the economic activities to urban areas from rural areas might decrease the unemployment rate.
- **Land:** Namibia is the second lowest densely populated country in the world because of large parts of the country being too dry for human settlement. A major issue to the socio-economic development is the land reform.
- **Economy**: Usually the country enjoys a steady economic growth of 4,6% per year but a severe drought slowed it down. The sectors mostly affecting the economic growth are agriculture, MSME, manufacturing, mining, and tourism.
- **Infrastructure:** There is a continuous scarcity of water in Namibia, where the demand is increasing and will keep on increasing as well. This is a major issue for Namibia. The electricity situation is sufficient in urban areas but lacking in rural areas. Besides, the country is highly dependent on neighbouring countries for the supply of electricity. The ICT infrastructure does not cover the whole country and facilities such as schools and health care do only in some cases have access to ICT services. The government attempts to improve the ICT infrastructure.

RQ3: "What is the current transport infrastructure situation in Namibia?"

Namibia's current transport infrastructure is relatively good and extended. The most advanced transport infrastructure is the road infrastructure, where the rail infrastructure needs improvement and extension to make it a more attractive modality for both passengers and freight. Although there are attempts to improve the current transport situation in terms of safety, social and economic problems and sustainability, reality is that the road sector will keep on investing in roads in the near future. This thesis focuses on the road infrastructure in Namibia only.

4
Spatial Data Analysis

This chapter aims to gain insights in the relationships between road infrastructure and economic growth, road safety, emissions and factors education, health, employment and tourism in Namibia. Chapter 2 gives an overview of relations as found in literature. This chapter attempts to confirm or to eviscerate these relations for the Namibia case by doing spatial data analysis on factors where data is available. These insights help developing a SD model to estimate the effects of improved road infrastructure on these factors. This chapter first shows the data handling process for this study, which includes the data gathering process and methods and the data preparation. Secondly, the method that will be used for to answer research question 4 is discussed. Thirdly, the relationships between road infrastructure and the different factors are investigated. The chapter concludes with the answer on RQ4, "What are the relations between road infrastructure, road safety, emissions, economic growth, education, health, employment and tourism in Namibia?".

4.1. Data handling

This section describes the data handling process for this study. Firstly, the data collection is discussed, which mostly comes from the 2011 census data. Secondly, this section explains how the data is prepared in order to enable performing the statistical tests.

4.1.1. Data collection

First of all, the census data is briefly introduced and secondly, the choice for the data-set of the road network in Namibia is substantiated.

Census data 2011

Namibia has conducted household surveys to obtain census data since its dependence in 1990. Every 10 years they make an attempt to have everyone fill out these surveys. This has lead to census data from 1991, 2001 and 2011. This research uses the information from the 2011 survey only, since there is only data of the road network of one moment in time. Since independence in 1990, the exact division of regions and constituencies has changed a bit; mostly in terms of the number of constituencies. In 1990, the first delimitation commission divided Namibia in 13 regions and 95 constituencies. Nowadays, the country has - as decided by the fourth delimitation commission in 2013 - 14 regions and 121 constituencies (Institute for Public Policy Research, 2015). The 2011 data has most of the recent constituency reformation incorporated and therefore this data-set is used. It should be noted that the rest of this thesis describes the most current *known* situation of Namibia - this can be from 2011 to 2019 - in order to get a full picture. The main used classification in the data-set is the region and constituency of individual inhabitants. This makes this data-set suitable for a multi-scale approach, which allows for tackling and solving problems which occur on multiple spatial and time-bound scales. Figure 4.1 shows an overview of the multiple scales in the data-set of Namibia. The final data-set - divided over three categories household, mortality and persons - contains 89 variables which can be found in appendix A. This data-set does not include all necessary data. Paragraph 4.1.1 discusses which extra data is needed and where it can be found. Besides, this data-set does not include the exact place of residence of individuals, hence the spatial distribution over the - often quite large - surfaces is unknown. Therefore, this research cannot make use of regular transport models that work with accessibility; to calculate accessibility, the place of residence is needed. For this reason, this research performs data analysis on a spatial level.

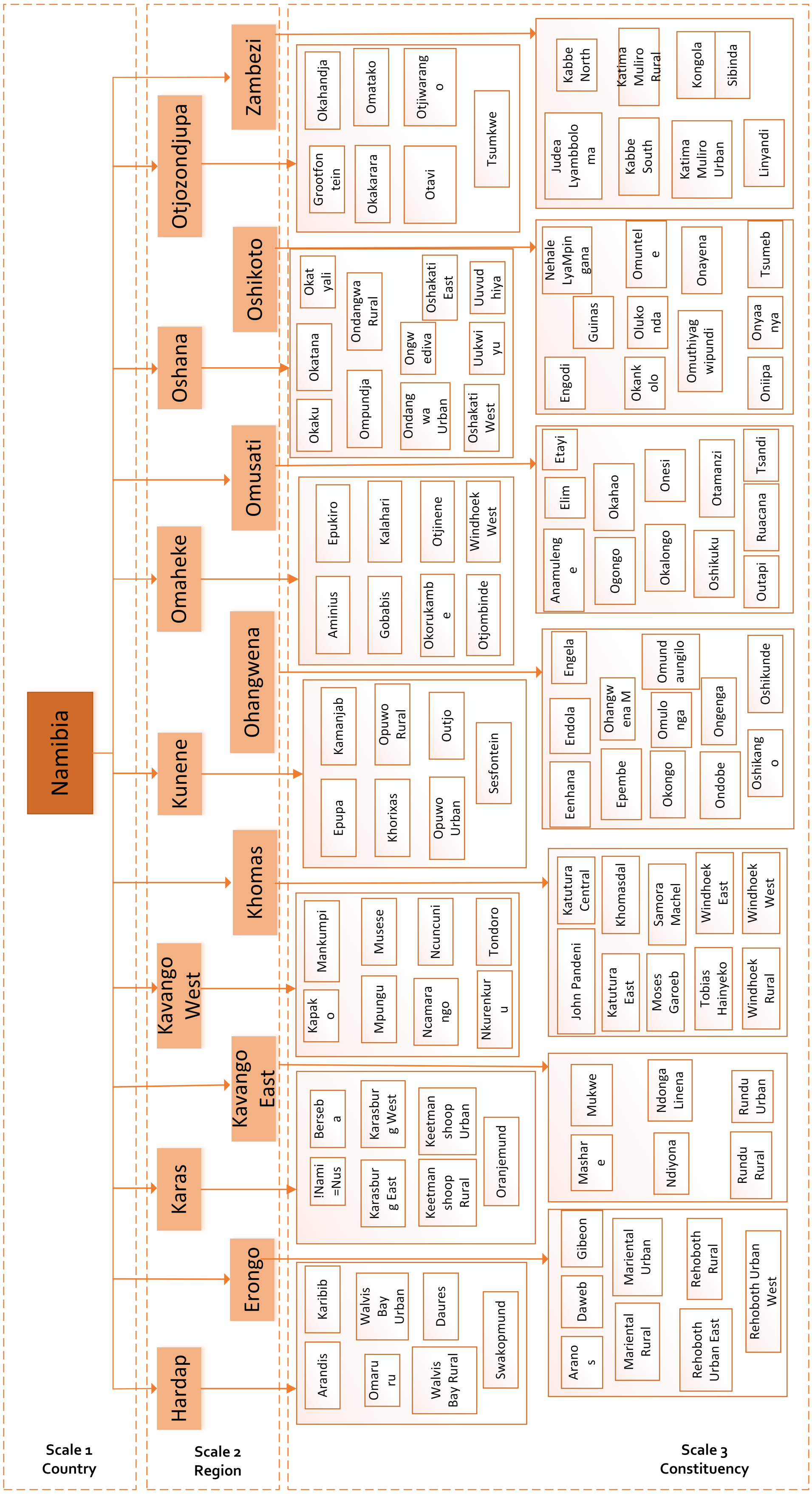


Figure 4.1: Multi-scale representation of Namibia

Multi-scale approach This approach has originally mostly been applied to the fields of chemical and material engineering. Since the 1990´s, applying multi-scale analysis to landscape and land-use problems has also proven to be useful. Burnett & Blaschke (2003) argue that natural complexity can best be explored as process continuums that can be partially decomposed into objects or patches, which in this case is the decomposition of Namibia into regions and thereafter into constituencies. According to De Koning et al. (1999), using a multi-scale approach enables capturing the spatial dynamics by taking variability into account between cells of a geographical grid that covers the entire study area. The model used for this research uses the specific characteristics of the different regions and constituencies from the available data and therefore the results will show region or constituency specific behaviour. O'Neill et al. (1986) recommend a minimum of three hierarchical levels in analytic studies. This research will mostly use the three layers of Namibia, its regions and each region's constituencies. The multi-scale approach proves to be very suitable and useful in the domains of this research. Applying the multi-scale approach is mostly beneficial in system dynamics (used in chapter 6).

Additional data

Not all information needed for the system dynamics model can be derived from the census data. The remainder data are mostly found in shapefile form and analysed by using GIS software. The list below shows the additional needed data and where the data come from.

Surfaces Regional profiles are available on the website of the NSA (NSA, 2019). These reports contain most of the surfaces in square kilometre per constituency according to the most recent delimitation (fourth). Some of these missing or changed values of these differences can be filled up with the help of government sources, news articles, and maps. The surfaces of the constituencies according to the old delimitation (third) are calculated in QGIS software. Shapefiles for each constituency according to the third delimitation can be found at http://www.maplibrary.org/library/stacks/Africa/Namibia/index.htm.

Education and health care facilities Information on both health care and educational facilities is derived from the Humanitarian Data Exchange (HDX) website (https://data.humdata.org/group/nam), where OCHA ROSA published a shapefile (updated last August 2018) on both health facilities as educational facilities. The updates of these files do not incorporate the new constituency division and therefore some values will remain unknown (such as number of facilities in a 'new' constituency).

Road network There are different sources that offer the Namibian road network in the form of a shapefile. These shapefiles differ quite a bit from each other. The choice of the road network data-set is substantiated in the subsection below.

Data analysis structure

Not all variables coming forward in figure 2.1 can be used for data analysis due to a lack of data. In order to be useful for data analysis, many cases are needed. Only data on constituency level would suffice for this requirement with 120 cases. The outcomes of the data analysis of the relations that can be investigated are used in the SD-model in chapter 6 and the missing relations are taken from literature as described in chapter 2.

Road network data-set choice

More and more institutions are openly publishing their information and therefore in the case of road network data, multiple data-sets were found. However, many of these readily available road data-sets - both public domain and commercial - contain positional errors or generalisations that may not be compatible with highly accurate geospatial locations (Frizzelle et al., 2009). To be sure of a data-set with no errors and high quality, one can generate such a data-set themselves. However, this is highly time consuming and nearly impossible if applied to a large study area. In this research, both time limitation and the big study area do not allow for producing a self-made road network data-set. Frizzelle et al. (2009) researched the importance of accurate road data for spatial applications and their study "serves as a guide for assessing the feasibility of readily available commercial or public road data-sets, explains their limitations, ...". They distinguish the following benefits and limitations of using prepackaged comprehensive road data in research studies:

Benefits	**Limitations**
Often cover very large areas	Often out of date
Associated attribute information is often clear and consistent	Often missing new roads
Often topologically sound (all roads are connected at intersections)	Often contain positional errors

Both these benefits and limitations depend on the purpose of the data-set and the goal of the research for which the data-set is used. Frizzelle et al. (2009) determine two points to consider when choosing if and which data-set one uses for their research: the purpose and the currency of the data-set. The purpose of a data-set includes the scale and the positional accuracy. There is a large difference between small-scale and large-scale data-sets. Small-scale data-sets usually cover very large areas which results in generalised features and larger positional error in their features. Large-scale data-sets, covering small areas, tend to have more detailed features and less positional error (Tomlinson, 2013). Secondly, the currency of the data-set. The importance of this depends on the study area and the dynamics of this area. If there are major changes in the studied area, the data will most probably not contain all roads needed and is therefore unusable. On the other hand, areas that do not experience much change in the road network can better handle older road data-sets (Frizzelle et al., 2009). Table 4.1 below shows the result of the search of a suitable publicly open data-set of the road network in Namibia. The source indicates the public domain where the data-set is found.

Table 4.1: Different publicly available data-sets of Namibia's road network

Source	**Year**	**Total road length**	**Relevant attributes**
DIVA-GIS https://goo.gl/Gv198j	Unknown	35684 km	Primary and secondary route
HDX - HOT https://goo.gl/ZBQA2B	2019	116051 km	• Type of road • Surface • Smoothness
Mapcruzin/OSM https://goo.gl/d3iV9n	Unknown	54379 km	Type of road
OCHA ROSA https://goo.gl/kcwWkv	2001	48450 km	Type of road
WFP GeoNode https://goo.gl/3oVt17	2018	117886 km	• Type of road • Surface • Road number/name

The year column shows *the most recent update*, not the original year of the generation of the data-set. This column shows two data-sets of which it is unknown when they were made or last updated, one made - and not been updated since - in 2001. The remaining two are last updated in 2018 and 2019, which is very recent. The purpose of all document was not explained in the included meta-data of the files. Therefore, this is not included in the table, although Frizzelle et al. (2009) mentioned this an important factor. One can still use the thought of most humanitarian organisations probably having certain purposes. On the HDX website, one can find dozens of different data-sets for each country. One can say that most of the data-sets published here are made for the purpose to cover a country and not a smaller region or city. As for the total road length one can basically distinguish two groups: 35000 - 55000 kilometres and 116000-118000 kilometres. The last column, relevant attributes, shows quite some difference as well. It must be mentioned that the sources with multiple attributes do not have full coverage for all these attributes. For instance, the WFP road network data-set includes surface type for 31% of all cases (24,284). Taking these points into account, it comes forward that the WFP and the HOT data-sets are the most recent, comprehensive and detailed. The main difference between the HOT and the WFP data-set can be seen in GIS software. The HOT data-set has more roads indicated in big cities than WFP where the WFP data-set has some more roads indicated along the border areas and more remote roads. This research uses road density as an important variable and this value in cities will be high with or without the 'extra' roads of the HOT. On the contrary, the road density in rural, remote areas can be very low and the extra roads that the WFP data-set indicates can be of greater difference and importance. Therefore, this research uses the WFP data-set. This data-set is used for all further analyses in this research.

4.1.2. Data preparation

As discussed in chapter 4.1, the raw 2011 census data include the fourth delimitation updates. Hence, this data set contains data of 14 regions and 121 constituencies. However, the data set does not contain all needed information, such as surface and information on roads. This section shows the data preparation which is done to have one complete data set of all the information for 121 constituencies. The list below describes how missing information in the 2011 data set is gathered and if needed, how it is converted to the most recent delimitation. The fourth delimitation has 14 new constituencies compared to the third delimitation, hence quite a bit has changed (Institute for Public Policy Research, 2015). Table 4.2 below shows the constituencies that the regional profiles on NSA (2019) did not include, how they are formed and how their surface is determined.

1. **Surface**
   Regional profiles are available from NSA (2019). These reports contain surfaces per constituency. Table 4.2 shows how the surfaces of the unknown constituencies are determined.

2. **Road network**
   The road network is available in the form of a shapefile. As determined, the WFP road network shapefile is used. Together with a shapefile of the boundaries of each constituency, the length of roads per constituency can be determined. This is done with a Python script in the Jupyter Notebook of the Anagonda software. However, the constituency shapefiles are made according to the old delimitation. Therefore, the output of the Python script is not fully covering the new delimitation. Table B.1 shows the old and new values of the road length and density per constituency. The road length for the new constituencies is determined in the same way as the surfaces, explained in table 4.2.

3. **Education and health facilities**
   The shapefiles of education (OCHA ROSA, 2018a) and health facilities (OCHA ROSA, 2018b) are also not entirely up to date with regards to the fourth delimitation. The visualisations that are shown in the corresponding paragraphs below are according to the old delimitation. With the information retrieved from the sources in the right-hand column of table 4.2, education and health facilities per constituency according to the new delimitation are calculated by hand in QGIS.

4. **School attendance**
   School attendance is in each region's census data, except for Kavango West. The not as much updated regional profile NSA (2019) indicates school attendance for the old Kavango constituencies and therefore the missing values of school attendance could be filled in according to the new constituency division explained in table 4.2.

5. **Nehale LyaMpingana**
   Except for the census data, nothing is to be found about Nehale LyaMpingana. Therefore, this constituency is not used in the data analysis and to correct for this with regards to the other constituencies in the region, the old population of each constituency is used instead of the new ones. The old populations can be found in the regional profile of Oshikoto (NSA, 2019).

Table 4.2: Constituencies which were not in the regional profiles based on census data 2011

Region	Constituency	Formed from..	Surface information
Hardap	Aranos	Marienthal Rural split into two constituencies: Marienthal Rural and Aranos. Aranos takes about 2/3rd and Marienthal Rural 1/3rd.	Immanuel (2013)
Hardap	Daweb	Gibeon split into two: Gibeon and Daweb. Daweb is about 3/4th of the old Gibeon.	Namibian map and Google maps
Karas	!Nami=Nus	Name change: !Nami=Nus is the old Lüderitz.	NSA (2019)
Karas	Karasburg East & West	Karasburg divided into an eastern and a western part. East takes up about 2/3rd of old Karasburg and west 1/3rd.	Immanuel (2013)
Kavango East	Ndonga Linena	Ndiyona split into Ndiyona and Ndonga Linena. The latter is about 1/3rd of the old Ndiyona and the new Ndiyona the rest.	Wikipedia, Google maps and Immanuel (2013)
Kavango East	Rundu Rural	Rundu Rural is former Rundu Rural East.	NSA (2019)
Kavango West	Mankumpi, Musese & Tondoro	Former Kahenge split into these three constituencies. Tondoro takes up half the old surface and Musese and Mankumpi 1/4th both.	Wikipedia, Google maps and Immanuel (2013)
Kavango West	Ncamagoro	Kapako split into Ncamagoro and Kapako. Ncamagoro is about 3/4th of the old Kapako. The other 1/4th is new Kapako.	Wikipedia, Google maps and Immanuel (2013)
Kavango West	Ncuncuni	Ncuncuni is former Rundu Rural West.	NSA (2019)
Kavango West	Nkurenkuru	Is part of Mpungu. Takes up about 1/20st of Mpungu.	Wikipedia and Google maps
Khomas	John Pandeni	Was Soweto.	NSA (2019)
Kunene	Opuwo Rural & Urban	Opuwo Urban is about 1/12th of total surface.	Immanuel (2013)
Ohang-wena	Oshikunde	Okongo split into Okongo and Oshikunde. The latter is about 1/4th of the old surface of Okongo.	Immanuel (2013)
Omaheke	Okorukambe	This is former Steinhausen.	NSA (2019)
Oshana	Ondangwa Rural & Urban	Ondangwa Urban is assumed to be just the city; about 15 km^2 of the total.	Assumption and Google maps
Oshikoto	Nehale LyaMpingana	Unknown	-
Zambezi	Judea Lyabboloma	Linyanti split into two equal parts: Linyanti and Judea Lyabboloma.	Wikipedia
Zambezi	Kabbe North & South	Kabbe split into two equal parts: North and South.	Wikipedia

4.2. Method

To identify the relationships between road infrastructure and different factors, data analysis is conducted. Since the data-set gathered through the census data is location-bounded (on constituency level), this data-set could be called a spatial data-set. Data on health and education facilities is also obtained in a spatial form. All data used for this research is secondary data, which is data that was collected by someone else for another primary purpose. Utilising this existing data is a viable option for research with limited time and resources, such as this research (Johnston, 2017). It should be noted that due to a lack of data and time, it is not possible to find all explaining variables for every factor. However, the aim of this chapter is to get insights in the relation between road density and all factors. Therefore, the remainder sections will not present fully comprehensive and accurate models, but use available data which is likely to be of predictive nature for the specific factor. To test the influence of these predictive variables including the road density, multiple regression analysis is performed. This section elaborates on statistical theories related to regression analyses first, where after the (multiple) regression analysis is explained. Having basic knowledge on relevant underlying statistical theory is important for understanding and interpreting the output of the models. Calculations are done in SPSS.

4.2.1. Statistical theory

Pearson's correlation coefficient *r* This coefficient gives information about the linear relation between two variables with the letter r. The value lies within 1 (perfect correlation) and -1 (perfect but negative correlation) and 0 denoting the absence of a relationship. Hence, the higher $|r|$, the stronger the relationship (Lee Rodgers & Alan Nice Wander, 1988).

Coefficient of determination R^2 This coefficient measures the proportion of the variance in the dependent variable. In regression analysis with only one independent variable, the coefficient is defined by the square of the Pearson's correlation r (hence r^2). The coefficient R^2 indicates the extent to which the independent variable determines the behaviour of the dependent variable. If it is exactly known how the dependent variable behaves by observing the independent variable, R^2 would be 1. This is very unlikely. If observing the independent variable does not tell anything about the behaviour of the dependent variable, the R^2 is 0 (Kahane, 2014).

Statistical significance Statistical significance indicates the probability that the difference between variation and the regression line is not due to random chance. Hence, a statistically significant outcome means that one can almost be sure that the observed results are reliable. Usually, the researcher chooses a confidence interval of 95%, which means that it 95% sure that the results are real and not an error caused by randomness. With the 95% confidence interval, the level of significance is 5%. In order to reject the null hypothesis saying that there is no regression coefficient, the p-value must be < 0,05.

4.2.2. Multiple regression analysis

The multiple regression analysis is used to explain the relationship between one continuous dependent variable and two or more independent variables. A multiple linear regression model demands a linear correlation between all independent or predictive variables and the variable that must be predicted (dependent variable). An example of a linear function is:

$$f(x_1, x_2, ..., x_n) = A_0 + A_1 \cdot x_1 + A_2 \cdot x_2 + ... + A_n \cdot x_n \tag{4.1}$$

All predictive variables (x_1,. . . x_n) (must) have a linear relationship with the predicted variable through coefficients A_1, . . . ,A_n. A_0 is the intercept.

If only one variable x_1 predicts the dependent variable , it is called a linear regression analysis, whereas having multiple predictive variables is called a multiple linear regression analysis. Hence, if for instance only road density would be used as a predictive variable for education, a linear regression analysis should be performed, where if schools per surface is considered additionally to road density, multiple linear regression analysis should be performed.

Assumptions

For this multiple regression analysis, several assumptions are used that the data needs to comply to. The list below describes these seven assumptions (Williams et al., 2013). It is indicated in the relevant chapters if all data satisfies the assumptions.

1. **Outliers**
   Preferably there are no outliers, since these can disturb the regression. Outliers can be detected and removed if done by proper testing. This can be done by using Mahalanobis Distances while performing linear regression. These values can help calculating the p-value of the right-tail of the chi-square distribution (Statistics Solutions, 2019). Constituencies with a lower p-value than 0,01 can be considered as outlier and are therefore removed from the data.

2. **Linearity in parameters**
   There must be a linear relationship between the dependent and the independent variables. This can be tested by making scatter-plots of the independent and dependent variables; one for each independent

variable and by looking at the correlation coefficient. If the scatter-plot or the correlation coefficient do not show a linear relationship, a transformation to the variables can be applied to make the relation linear. Table 4.3 gives some examples of transformations (Stat Trek, 2019).

Method	Transform	Regression equation	Predicted value $\hat{y}$
Standard linear regression	None	$y = b_0 + b_1 \cdot x$	$\hat{y} = b_0 + b_1 \cdot x$
Exponential model	$log(y)$ $ln(y)$	$log(y) = b_0 + b_1 \cdot x$ $ln(y) = b_0 + b_1 \cdot x$	$\hat{y} = 10^{b_0 + b_1 \cdot x}$ $\hat{y} = e^{b_0 + b_1 \cdot x}$
Quadratic model	$\sqrt{y}$	$\sqrt{y} = b_0 + b_1 \cdot x$	$\hat{y} = (b_0 + b_1 \cdot x)^2$
Reciprocal model	$\frac{1}{y}$	$\frac{1}{y} = b_0 + b_1 \cdot x$	$\hat{y} = \frac{1}{b_0 + b_1 \cdot x}$
Logarithmic model	$log(x)$	$y = b_0 + b_1 \cdot log(x)$	$\hat{y} = b_0 + b_1 \cdot log(x)$
Power model	$log(y)$	$log(y) = b_0 + b_1 \cdot log(x)$	$\hat{y} = 10^{b_0 + b_1 \cdot log(x)}$

Table 4.3: Examples of transformations

3. **Zero conditional mean of errors**
   This can be tested by plotting a scatter-plot of standardised predicted values versus standardised residuals. If the values do not differ visibly from 0 across the range of standardised estimated values, the variables comply to this assumption.

4. **Independence of errors**
   This can be tested with the same scatter-plot as for assumption 3; if there is no obvious pattern indicating that the residuals would be influencing one another, one can assume independence of errors. However, in general this problem occurs in data with time series, where data from different moments in time appears to be dependent on each other. The data used for this study does not include time series and therefore the independence of errors can be assumed.

5. **Homoscedasticity (constant variance) of errors**
   This implies that the error term of the predicted dependent variable is the same across all values of the independent variables (Statistics Solutions, 2013). The same scatter-plot as for assumption 3 can be used to see if the residuals have a constant variance.

6. **Normal distribution of errors**
   This is needed in order to determine the statistical significance. A histogram can be plotted of the standardised results to see if the errors are more or less normally distributed.

7. **No multicollinearity**
   Collinearity is the presence of correlation between predictors (independent variables), which is not desirable. It creates "shared" variance between independent variables, which decreases the ability to predict the dependent variable (Hair Jr et al., 2014). Multicollinearity can be identified by analysing the Variance Inflation Factor (VIF) and the collinearity diagnostics table (Laerd statistics, 2019). The VIF values can be obtained from the output of a linear regression. The value of independent variable x is an indicator of the effect that the other independent variables have on the standard error of the regression coefficient of x. A cut-off limit of 10 is often used; a VIF of > 10 is cause for concern (Hair Jr et al., 2014). Eigenvalues of the collinearity diagnostics table indicate multicollinearity when close to zero, which means that small changes in data values may lead to large changes in the estimates of the coefficients.

Another rule of thumb for multiple regression analysis is that for each predictor there should be more or less 15 observations. This means that each model can have $120/15 = 8$ predicting variables in this case-study with 120 constituencies.

4.3. Road Infrastructure

The road infrastructure in Namibia is extensively discussed in chapter 3.3. One of the measures mostly used by researchers to assess road infrastructure is road density (Cervero & Murakami, 2010; Su, 2011). This is not the most comprehensive and explaining variable, but with a lack of data it is the best indicator for road infrastructure. Figure 4.2 below shows an overview of the road density for each constituency. It represents the length of the road in kilometre (km) per each constituency's surface in square kilometre (km^2). These values are derived from the chosen data-set as described before and a shapefile defining all constituency borders. A full table with the value per constituency can be found in appendix B. Logically, the urban areas have a

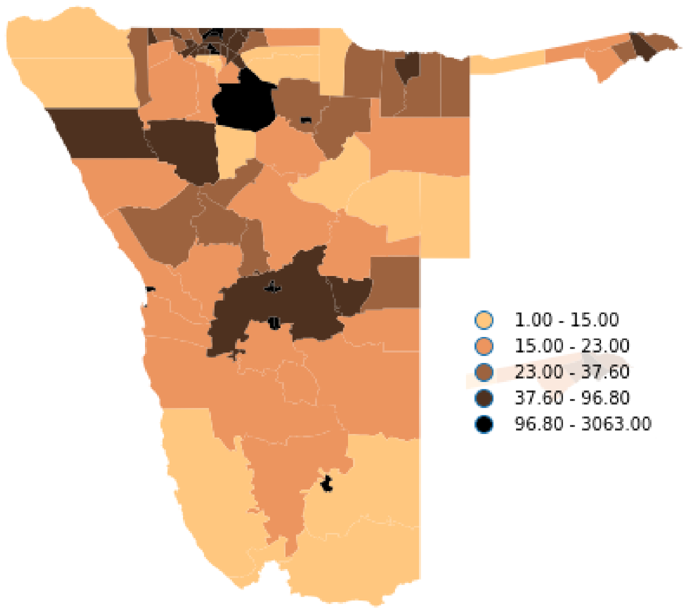


Figure 4.2: Road infrastructure density per region in km/km^2

high road infrastructure density whereas some parts of the - rural - country have low densities. The average weighted road density is 0,140 km/km^2. The average is weighted for surface, so the bigger the constituencies the more it weights in calculating the average road density. The non-weighted average of road density is 0,670 km/km^2. Most of the road densities lie between 0 and 1 km road per square kilometre surface. This research uses the road density to indicate level of rural or urban. All constituencies with a road density lower than or equal to 1 are considered to be rural, between 1 and 4 are semi-urban and above 4 is considered urban. The road density variable is a continuous variable, which means that the variable can take any value, as opposed to a discrete variable.

4.3.1. Road quality per region

A report by the RA shows the material type of road per region. The shapefile consists of a lot more kilometre road than this report indicates (this can be caused by numerous reasons) and that is why table 4.4 shows the percentages of type of road instead of absolute numbers. The *B* implies bitumen, the *G* gravel, the *S* salt and the *E* earth roads. The first column shows that all trunk roads only consist of bitumen. The road length of trunk roads is relatively small. The column bitumen of the total does not include the bitumen of trunk roads because this is not a good representation. Furthermore, the table indicates that there is quite a difference between the proportions of road type between the regions. For instance, the Kavango regions have a very low quality of roads compared to the Oshikoto region. In general one can see that the main roads have better quality (more bitumen) roads than the district roads. Unfortunately this data is only available on region level and not on constituency level. Using the region proportions of road type on constituency level points out that there is no correlation between the proportion of for instance bitumen and school attendance. Since the data-set only contains 14 different values (of the regions), this is not a surprising outcome. One needs a more detailed data-set on constituency level to properly test for correlation between road type and school attendance.

Table 4.4: Division of road types per constituency, adjusted from Roads Authority (2017)

Region	Trunk roads	Main roads				District				Total			
	B	*B*	*G*	*S*	*E*	*B*	*G*	*S*	*E*	*B*	*G*	*S*	*E*
Karas	100%	17%	82%	0%	1%	1%	71%	0%	28%	17%	65%	0%	18%
Erongo	100%	7%	80%	12%	0%	0%	45%	7%	48%	13%	50%	8%	29%
Hardap	100%	11%	88%	0%	1%	2%	65%	0%	33%	10%	69%	0%	21%
Kavango East	100%	0%	0%	0%	0%	2%	40%	0%	58%	23%	31%	0%	45%
Kavango West	100%	0%	0%	0%	0%	1%	26%	0%	73%	34%	17%	0%	49%
Khomas	100%	10%	86%	0%	4%	1%	57%	0%	42%	13%	63%	0%	24%
Kunene	100%	35%	65%	0%	0%	0%	53%	1%	46%	11%	56%	0%	33%
Ohang-wena	100%	73%	10%	0%	17%	3%	47%	0%	51%	35%	31%	0%	34%
Omaheke	100%	3%	90%	0%	7%	0%	47%	0%	53%	18%	54%	0%	28%
Omusati	0%	100%	0%	0%	0%	4%	38%	0%	58%	37%	25%	0%	38%
Oshana	100%	93%	7%	0%	0%	4%	57%	0%	40%	23%	46%	0%	31%
Oshikoto	100%	100%	0%	0%	0%	3%	72%	0%	25%	29%	53%	0%	19%
Otjozon-djupa	100%	12%	85%	0%	3%	0%	66%	0%	34%	16%	61%	0%	23%
Zambezi	100%	100%	0%	0%	0%	3%	26%	0%	71%	35%	18%	0%	48%

4.4. Education

This section discusses the relevant education data used for the data analysis and the execution of the data analysis itself. It aims to identify the relationship between road infrastructure and education in Namibia.

Education overview

As explained before, the education system is divided in primary, secondary and tertiary education. The used shapefile includes primary, secondary or combined schools. However, the differences in the amounts of education facilities per type are negligible. Therefore, figure 4.3 shows an overview of all education facilities in each constituency. A darker colour means a higher intensity of education facilities. The figure shows a huge

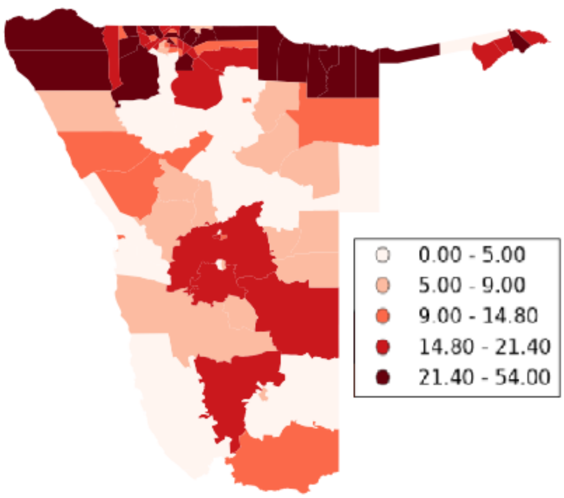


Figure 4.3: Primary education facilities per constituency

difference in education facilities between the constituencies. The division of people over Namibia (figure 3.2) is quite similar to the division of education facilities. However, fact remains that some - large - constituencies do only have 0 to 5 education facilities which is very low, especially since this map is not related to surface.

One can see that some of the bigger constituencies such as Lüderitz (left-bottom) and Omatako (centre) only have zero to five education facilities. This is a very low amount for the size of the constituency. It is very likely that not everyone has sufficient access to these facilities, mostly in terms of travel time. Some constituencies have a high population density and little supply of education facilities, such as Walvis Bay Rural and Oranjemund. The majority of people in Walvis Bay Rural still live close to Walvis Bay Urban and therefore have access to facilities within a foreseeable distance. Due to the scope, perspective and time limitation of this research, it is not possible to perform a full and complete analysis of the education level and quality in Namibia. A logical indicator to measure the relationship between road infrastructure and education is education enrolment. Brenneman & Kerf (2002) researched transportation impacts on poverty across many different (developing) countries. An overall finding is that rehabilitated roads and new roads and the proximity of these roads result in an increase in enrolment (Morocco, Zambia, Ghana, Peru and the Philippines). This is also one of the indicators used by the fourth SDG, to "ensure inclusive and equitable quality education and promote lifelong learning opportunities for all" (United Nations, 2018b). Education attendance or enrolment is also a widely used indicator for education quality or education performance (Barrett et al., 2006; Cheng & Tam, 1997). The universally used Education for All Development Index (EDI) - a composite indicating to what extent a country succeeds in providing education for all - uses education enrolment, literacy rate, survival rate up to grade 5 and gender parity in primary and secondary education (Dronkers & de Heus, 2016; Unesco, 2015). The first two determinants for this EDI are given in the census data. The latter two are unknown, but one can conclude that education enrolment and literacy rate indicate some level of education quality and performance. The data on Namibia provides information on different enrolment levels, but for the best overview of the situation now, the primary school enrolment for children between 7 and 13 is taken. If, for instance, the percentage of population that never attended school would be used, it would include older population that never attended school and hence it would not give a proper representation of the situation now. Table B.2 in appendix B gives a complete list of primary education enrolment and literacy rate per constituency. Table 4.5 shows the fifteen constituencies that have the lowest primary enrolment rate and the accompanying population- and road density. The bottom row, average of all constituencies, is the *weighted* average. This means that it is not the average of all density values but the average with regards to surface. Hence, the bigger a constituency, the more it weighs in the average.

Table 4.5: Fifteen constituencies with the lowest primary school enrolment rate

Constituency	**Region**	**Population density [people/km2]**	**Road density [km/km2]**	**Primary school enrolment**	**Literacy rate**	**Number of schools (#)**
Kapako	Kavango West	13,24	0,065	79,1%	76,2%	10
Ncamagoro	Kavango West	1,53	0,194	79,1%	63,3%	24
Windhoek Rural	Khomas	0,52	0,307	79,9%	86,6%	15
Epupa	Kunene	0,75	0,090	25,4%	29,4%	22
Kamanjab	Kunene	0,49	0,289	72,1%	75,4%	4
Opuwo Rural	Kunene	0,61	0,096	54,9%	47,5%	14
Opuwo Urban	Kunene	6,00	0,139	54,9%	74,0%	11
Sesfontein	Kunene	0,42	0,146	77,3%	72,4%	6
Kalahari	Omaheke	0,62	0,190	66,4%	58,1%	7
Okorukambe	Omaheke	0,58	0,109	66,9%	65,7%	3
Otjombinde	Omaheke	0,36	0,042	74,6%	64,1%	3
Guinas	Oshikoto	0,53	0,158	64,9%	60,0%	5
Grootfontein	Otjozondjupa	2,21	0,165	76,5%	80,5%	9
Otavi	Otjozondjupa	0,88	0,130	69,4%	72,8%	5
Tsumkwe	Otjozondjupa	0,35	0,133	59,1%	57,6%	10
Average of all constituencies		**2,54**	**0,140**	**87,5%**	**87,8%**	**12,7**

The first thing that stands out is that for four regions, multiple constituencies have a primary school enrolment rate lower than 80%. Especially Kunene (five constituencies total) and Omaheke and Otjozondjupa (both three constituencies total) perform bad. Most constituencies either have a very low densely road infrastructure or a little number of schools. As came forward in chapter 2.3.2, topography - measured in distance to nearest school - majorly affects school attendance and enrolment in rural areas. Low densely road infrastructure most probably implies that the distances are, on average, longer than if there would be a higher densely road infrastructure. Hence, school enrolment is most likely majorly dependent on the availability of facilities and the accessibility to these facilities. The presented table and highlighted features are meant to give a sense of the available data on education. The next section performs data analysis to identify the actual relationships between road infrastructure and education.

Education spatial statistical analysis

Figure 4.4 shows a scatter-plot with the values for road density and primary education enrolment on a two-dimensional graph. As mentioned before, the road density values mostly lie between 0 and 1 and the few high values make analysis difficult. The figure below has excluded all urban areas, hence all values of road density above 4, and the 'primary school attendance' (PSE) values lower than 0,5 to see the division of the majority of the cases more precisely, hence solely for the visual purpose. One can see that the cases are quite spread

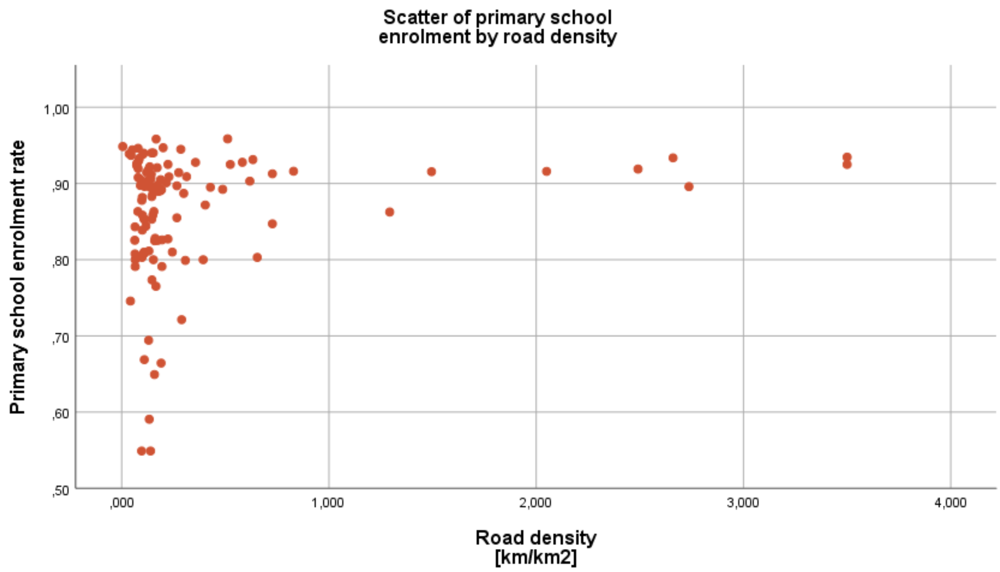


Figure 4.4: Scatter-plot of the road density on x-axis and primary school enrolment percentage on the y-axis

out over the x-axis and y-axis. Most semi-urban constituencies - constituencies with a road density between 1 and 4 km/km^2 have a primary school attendance of 90% or higher. In rural areas (< 1 km/km^2), one can see that the school attendance varies between constituencies, but that all cases performing poorly on school attendance are in the left hand-side of the x-axis, which implies they have a low road density. Data cannot explain why some constituencies with a low road density have a good education enrolment and some do not. There can be multiple reasons for this and chapter 5 investigates constituencies with low road densities and discrepant performances on all factors to get insights in the differences in performance.

To test the relation between road infrastructure and education with the help of multiple regression, other explaining variables on a spatial level must be included. Chapter 2.3.2 provided a framework for other explaining variables of education enrolment than accessibility. Due to the limited provided data, it is not possible to include all these explaining variables for education enrolment. The first one includes child characteristics, which is not measured in the household survey; it contains the number of people going to school in a certain constituency, but does not link individual characteristics to the school enrolment. Therefore, child characteristics cannot be included in this case-study. The same goes for household characteristics education wise. The last one includes determinants on the welfare of household, such as income level household members and asset ownership, explained by number of rooms per house, material of the wall and ownership of dwelling unit. The material of the walls is included in the provided data-set, so the material of the wall can be used as a predictor for education enrolment. The data distinguishes cement blocks/brick, burnt bricks/face bricks, mud/clay bricks, corrugated iron/zinc, prefabricated materials, wood poles/sticks or grass/reeds, sticks with mud/clay cow dung and tin, of which the latter six are considered to be a sign of low asset ownership. According to figure 4.11, there are no correlations between education and health or education and employment. Lastly, apart from road density, the availability of educational facilities is likely to be a predictive variable in terms of accessibility. Similar to road length; one cannot derive much information from the absolute number of facilities per constituency, since the sizes of constituencies vary a lot. Therefore, the number of educational facilities per surface is used.

As for the multiple regression analysis, the data should comply to several assumptions. First of all, the education data must be checked for outliers. Chapter 4.2 describes a way of doing this, and in this case this method is used for the primary school attendance rate, the road density, the schools per surface and the wall material. This resulted in deleting five constituencies: Epupa, Katutura Central, Katutura East, Ondangwa Urban and Walvis Bay Urban. Secondly, one should check for individual linearity in parameters, which is done by four scatter-plots: road density, the second of schools per surface, the U5MR predicting and the material of walls predicting primary school enrolment. Figure B.1 in appendix B.3 shows these scatter-plots. Besides, regression analysis gives a positive significant coefficient of road density predicting primary education enrolment (B = 0,187, p = 0,045). This implies that a higher road density on average causes a higher primary education enrolment rate. The second regression analysis gives a positive significant coefficient of schools per surface predicting primary education enrolment (B = 0,345, p = 0,003). This means that more schools per surface lead to a higher primary education enrolment. The U5MR has an insignificant regression coefficient for primary school enrolment (B = -0,150, p = 0,109) and is therefore not used as a predictive variable for school enrolment from now on. The material of walls has a significant regression coefficient of -0,279 (p = 0,003) predicting primary school enrolment. This implies that the higher the ratio of people not having walls considered to be an asset, the lower the primary school attendance. Lastly, the ratio of earth roads has a significant coefficient for primary school enrolment (B = 0,193 and p = 0,034) but the positive sign of the coefficient is not logical; this would imply that the higher the ratio of earth roads relative to gravel and bitumen, the higher the primary school enrolment. For this reason, this variable is left out from the analysis.

The third, fourth and fifth assumption are tested by looking at the scatter-plots in figure B.2 in appendix B.3. The cases are spread out over the x-axis on both side of the vertical zero line for all three variables and hence the mean of the errors is more or less zero. From the same scatter-plot one can assess the independence of errors, although it is assumed to be true. All three figures do not show obvious patterns indicating that the residuals would be influencing one another, hence independence of errors can be assumed. The fifth assumption is the homoscedasticity of errors, which means that the errors have a constant variance, which is not desirable. The scatter-plots show that the errors do have a constant variance, which means that there is homoscedasticity.

The sixth assumption is the normal distribution of errors, which can be seen in figure B.3 in appendix B.3. The last assumption is that of no multicollinearity. This can be tested with the VIF test (should be < 10) and the tolerance test (should be > 0,1). All three variables meet these requirements, which means that these variables do not correlate. Hence, the (data of the) three variables comply with all assumptions that are made when doing a multiple regression analysis. This means that a multiple regression analysis can be performed with these variables and primary school attendance. The output of conducting the multiple regression with the remaining variables can be seen in figure 4.5.

Coefficients[a]

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.	Collinearity Statistics	
		B	Std. Error	Beta			Tolerance	VIF
1	(Constant)	,900	,021		42,103	,000		
	Road density [km/km2]	-,002	,012	-,017	-,137	,891	,508	1,970
	Schools per surface	,274	,161	,218	1,698	,092	,484	2,067
	WallMaterial	-,078	,034	-,213	-2,263	,026	,897	1,115

a. Dependent Variable: PrimaryAttendance

Figure 4.5: Multiple regression analysis for primary education enrolment

The overall model fit is significant and hence it can be concluded that the regression model fits the data better than the model without independent variables. The R^2 is 0,341 which means that this model explains the primary school attendance for 34,1%. Road density has a very small negative impact on primary school enrolment when combined with the other three variables. The coefficient is far from significant (p = 0,891). As for the magnitude of coefficients, material of the walls is a derivative of ownership of assets, which generally correlates with income. Hence, it is logical that this a way better predictor of education enrolment than accessibility variables (road density and schools per surface). The overall model fit is significant (p = 0,001), hence it can be concluded that the regression model fits the data better than the model with no independent variables. The regression model gives the following formula, obtained through the unstandardised coefficients from figure 4.5:

$$PSE(\%) = 0,9 - 0,002 \cdot RD + 0,274 \cdot EduFacSurf - 0,078 \cdot WM \tag{4.2}$$

In which RD is road density, EduFacSurf represents the educational facilities per surface and WM is wall material. One can see that only the wall material comes in as a significant variable and road density and schools per surface insignificant. This is often caused by multicollinearity, but this is excluded by the VIF and tolerance tests. However, a Pearson correlation test between road density, material of wall and schools per surface give significant correlations (figure 4.6).

Table 4.6: Correlations of independent variables predicting primary school enrolment

		Road density	Material of walls	Schools per surface
Road density	Pearson correlation	1	-0,242	0,701
	Sig. (2-tailed)		0,009	0,000
Material of walls	Pearson correlation	-0,242	1	-0,320
	Sig. (2-tailed)	0,009		0,000
Schools per surface	Pearson correlation	0,701	-0,320	1
	Sig. (2-tailed)	0,000	0,000	

The best option is to remove the highest correlating variable, which can be checked by looking at the VIF scores in figure 4.5 and in table 4.6. The higher the VIF score the more signs of correlation between the variables and schools per surface has the highest VIF (2,067). Similarly, the correlations of schools per surface with the two other variables are the highest. Therefore, this variable is excluded from the multiple regression analysis. Performing a new regression analysis with the material of the walls and road density as independent variables to predict dependent variable primary school enrolment gives a significant overall fit (p = 0,004) and the following new formula:

$$PSE(\%) = 0,909 + 0,012 \cdot RD - 0,091 \cdot WM \tag{4.3}$$

Road density still has an insignificant coefficient (p = 0,173) but it is a much lower p-value than with the former regression analysis. The model can be used as such - so including the insignificant coefficient - for several reasons; firstly, the overall model fit is significant, which could for instance mean that the coefficients are jointly not all equal to zero while the tests for individual coefficients could determine that some of them are individually equal to zero. Hence, the model in total significantly explains the primary school enrolment, even though not all separate coefficients are significant. Secondly, singular linear regression showed a significant linear relation between both road density and primary school enrolment, so a significant relation between the variables exists.

4.5. Health

In this section, the relevant health care data used for the data analysis and the execution of the data analysis itself are discussed. It aims to identify the relationship between road infrastructure and health in Namibia.

Health overview

As explained before, the education system is divided in primary, secondary and tertiary education. The used shapefile includes primary, secondary or combined schools. However, the differences in the amounts of education facilities per type are negligible. Therefore, figure 4.3 shows an overview of all education facilities in each constituency. A darker colour means a higher intensity of education facilities. Figure 4.6 shows a visualisation of health facilities per constituency in Namibia. Darker colours mean a higher intensity of health facilities. No distinction is made between type of health facility (hospital, clinic or health centre) and governmental or privately owned facilities. This map indicates that there is quite a big difference between

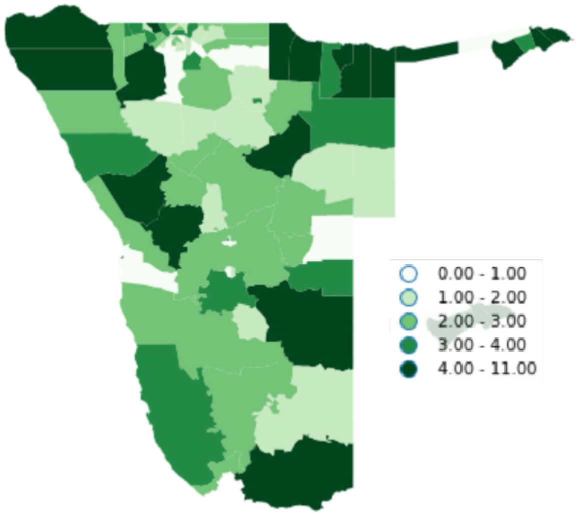


Figure 4.6: Health facilities per constituency

constituencies in terms of health care supply. First of all, Windhoek (centre) is light coloured which would mean there are no or little health care facilities. This is due to the fact that the city of Windhoek is divided into seven constituencies, of which some do not have health facilities within their boundaries. However, people in these constituencies do still have easy access (in terms of geographical accessibility) to health care. Secondly, some of the bigger constituencies only have between 0 and 2 health facilities for the whole constituency. This means that most probably, a large part of the constituency does not have easy geographical access to health care.

The same as for education goes for health care; due to limitations in time and scope and a different perspective (transport), it is not possible to perform a full analysis on the health status in Namibia. One indicator for health that is related to accessibility is the under-five mortality rate (U5MR). Schoeps et al. (2011) found that the U5MR is highly dependent on the accessibility of health care for an individual. Their findings emphasise the importance of geographic accessibility of health care for child survival in sub-Saharan Africa and show the need to improve the accessibility of health-care. U5MR is also used as an indicator for the third SDG, to "ensure healthy lives and promote well-being for all at all ages" (United Nations, 2018a). Besides, U5MR as a measure to assess health is an often used measurement by academic researchers as well (Elgar et al., 2015; Gwatkin et al., 2007; Hosseinpoor et al., 2016). Under-five mortality is commonly measured by number of deaths per 1000 live births (United Nations, 1990). Alkema & New (2014) state that the U5MR is "a key barometer of the well-being of a country's children and, more broadly, an indicator of socioeconomic progress". Table B.2 in appendix B shows the under five mortality of each constituency in Namibia. Table 4.7 below shows a list of constituencies that have a U5MR of over 100 deaths per 1000 live births. The average is weighted just as in the education table. The U5MR is weighted for population. It should be noted that the exact computation of a country's U5MR is more complex and takes more variances and errors into account. Alkema & New (2014) describe which formulas they use to acquire the U5MR, which is used by the UN. The UN value solely gives a national average and this research aims to make a distinction between the different constituencies to get insight in which constituencies perform relatively bad compared to the other constituencies. The U5MR in the table below is calculated by dividing the deaths of children of 0 until 5 (so 5 year old's not included) in the past 12 months (from household survey 2011) by the births in the past 12 months (same survey). This results in a unit is than deaths per 1000 live births. The average of all constituencies is 71 where the UN estimated an average of 52 in 2011 (UN Inter-agency Group for Child Mortality Estimation, 2018). This is a big difference and therefore the average U5MR as calculated for this research is not used to compare to other countries but solely to make a distinction between the constituencies.

Firstly, one can see that mostly the Kavango and Zambezi constituencies perform bad on the U5MR with a maximum of 315 deaths per 1000 live births. These constituencies are all located in North-west of Namibia.

Table 4.7: The under-five mortality rate over 100 deaths per 1000 live births

Constituency	**Region**	**Population density [people/km^2]**	**Road density [km/km^2]**	**U5MR [deaths per 1000 live births]**	**Number of health facilities (#)**
Daweb	Hardap	0,15	0,110	200,0	2
Keetmanshoop Rural	Karas	0,19	0,109	113,6	2
Mukwe	Kavango East	5,03	0,195	199,3	11
Ndiyona	Kavango East	1,56	0,108	124,2	4
Rundu Rural	Kavango East	7,04	0,266	101,0	2
Mankumpi	Kavango West	1,53	0,393	101,6	1
Musese	Kavango West	6,84	0,065	187,0	4
Nkurenkuru	Kavango West	17,39	0,654	144,0	1
Khorixas	Kunene	0,59	0,145	177,4	4
Outjo	Kunene	1,67	0,131	130,9	2
Judea Lyaboloma	Zambezi	2,92	0,155	110,5	3
Katima Muliro Rural	Zambezi	6,87	0,215	117,0	6
Kongola	Zambezi	1,45	0,108	105,3	1
Linyanti	Zambezi	3,88	0,078	314,7	2
Sibinda	Zambezi	6,54	0,099	102,6	4
Average of all constituencies		**2,54**	**0,140**	**70,8**	**2,72**

Secondly, almost all constituencies that perform bad on the U5MR either have a limited amount of facilities or low road density or a combination of these two. As came forward in chapter 2.3.1, road transport plays an essential role in providing access to health, especially in developing countries. Low densely road infrastructure most probably implies that distances to health facilities are, on average, longer than if there would be a higher densely road infrastructure.

The figure, table and highlighted features are meant to give an overview of the available (spatial) data on health care. The next section performs data analysis to determine the relationships between road infrastructure and health care.

Health care spatial statistical analysis

The scatter-plot in figure 4.7 shows the values for both variables on a two-dimensional graph. Again, some extreme values are excluded in this scatter-plot: road densities higher than 4 and U5MR above 200. These values are taken into account in further analysis. The values are quite spread out over the x-axis and y-axis, although one can see that all cases with a high U5MR have a low road density. All extremely bad cases in terms of U5MR - larger than 102 - have a road density lower than 0,216 (except for Nkurenkuru, which has a bad U5MR and relatively high road density). This implies that a higher road density decreases the U5MR when the value is exceptionally high.

To test the relation between the U5MR and the road density, other explaining variables on a spatial level must be included. Chapter 2.3.1 provided a framework for other explaining variables for child mortality than accessibility. However, this research heavily relies on the available data and therefore not all explaining variables can be identified and used. For instance, there is no data on childhood underweight, the first explaining variable as presented in figure 2.2. There is data on the second predicting variable unsafe water and sanitation for both water and sanitation. It shows that a lot of people do not have access to any toilet facility and to safe water in Namibia. However, water access and toilet access are correlated and therefore only one of these variables is included in the following steps. Water access has a stronger relation with U5MR (B = 0,319, p = 0,000) then toilet access (B = 0,209, p = 0,25). Hence, water access is used for this analysis. The third predicting variable according to the framework is that of indoor pollution from household use of solid fuels. There is data on the energy used for cooking of which the ratio of people using paraffin/kerosene, wood/charcoal

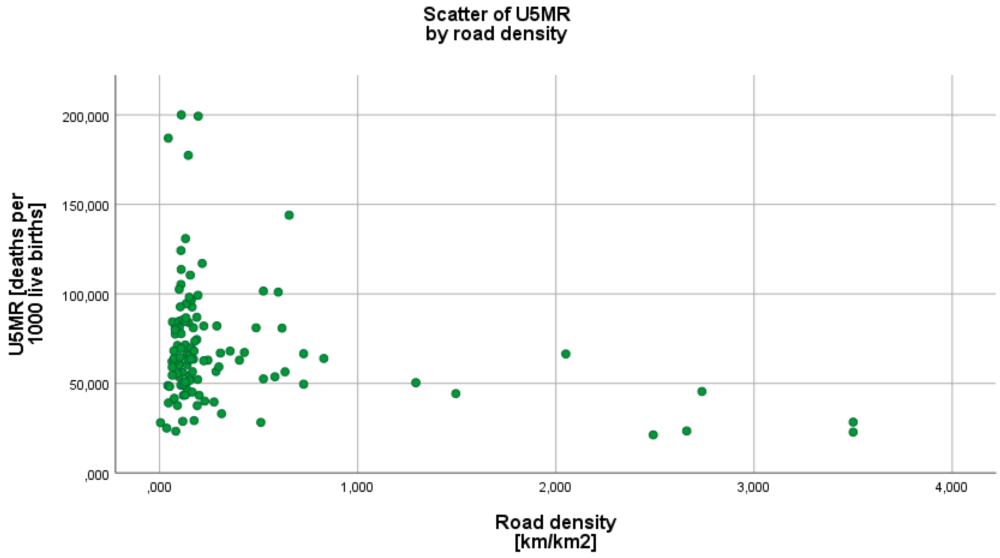


Figure 4.7: Scatter-plot of the road density on x-axis and the U5MR rate on the y-axis

from wood, charcoal-coal or animal dung is determined. These sources for cooking imply a high pollution and therefore this is used as the variable for high air pollution from household use. However, this variable too correlates with water access and is a smaller predictor for U5MR than water access and is therefore eliminated from the analysis. The fourth predictive variable is vehicle ownership and fatality rates. There is data on the vehicle ownership on constituency level. Furthermore, figure 4.11 shows an interrelation between health and employment in the Namibian data. However, this relation is not to be found uniformly defined in literature; there is not much research on the coherence between these two variables and the existing researches are mostly focused on precarious employment which is not included in the data, or on suggestions for further research on the relation between these two variables. Therefore, employment is not included in the multiple regression analysis. Lastly, apart from these predictive variables, accessibility of facilities is determined by facilities per surface, road density and the ratio earth roads of the total road length. To capture the effect of all these relations, multiple regression analysis is done. To perform this analysis, the used data and variables have to comply to the stated assumptions in chapter 4.2. First of all, the health data must be checked for outliers, which is done for road density, U5MR, health facilities per surface, and access to water. The procedure as described in the assumption list results in eliminating the five constituencies Kapako, Katutura Central, Linyanti, Ondangwa Urban and Walvis Bay Urban.

Secondly, the linear relation between all the variables and U5MR separately must be checked. Figure B.4 in appendix B.3 shows the linear relation between all five independent variables and the U5MR. All figures seem to show a linear relation between the variables and the U5MR. However, performing a linear regression can give a definite answer. The analysis gives significant linear output for road density and U5MR have a linear regression coefficient B = -0,220 (p = 0,0218), in which the minus sign indicates that the higher the road density, the lower the under-five mortality rate. There is no significant linear relation between health facilities per surface and U5MR; p=0,122. Therefore, the relation between facilities and the U5MR is not taken into account anymore. The third variable, safe water access has a linear regression coefficient of 0,370 (p = 0,001), which indicates that the more people do not have access to safe water, the higher the U5MR. Lastly, the effect of car ownership on U5MR comes out insignificant, B = 0,158 (p = 0,092). Besides, the sign of the coefficient does not make sense; right now the coefficient implies that if the ratio of people owning a car is higher, the U5MR increases. It would be more logical if the U5MR decreases if more people own a car. The ratio of earth graded roads has a significant effect on the U5MR; B = 0,407 and p = 0,000. This says that the higher the ratio of earth roads is (relative to bitumen and gravel), the higher the U5MR. Hence, the quality of the road largely influences the U5MR. Hence, road density and access to water are still considered to be predictors for U5MR and facilities per surface is eliminated.

The third, fourth and fifth assumption can be tested by looking at the scatter-plot of standardised predicted values and residuals. These scatter-plots of road density and U5MR, safe water access and U5MR and ratio of earth roads and U5MR can be seen in figure B.5 in appendix B.3. The mean of error of the standardised predicted value does not visible differ from zero. Therefore, the variables comply to the third assumption. There is no obvious pattern of residuals influencing each other, so one can assume the independence of errors. The figures show a constant variance of errors along the x-axis. Hence, from the scatter-plots in figure B.5, the third, fourth and fifth assumption are verified. The sixth assumption is that of the normal distribution of the errors, which can be seen in figure B.6. All three figures show a normal distribution of the errors the variables also comply to this assumption. The last assumption is that of no multicollinearity, which is not present between the two remainder variables; the tolerance is > 0,1 and the VIF values are between 1,30 and 1,81 (should be < 10). With all assumptions checked for these two variables, a multiple regression analysis can be performed. This means that a multiple regression analysis can be performed with these variables and primary school attendance. The output of conducting the multiple regression with the remaining variables can be seen in figure 4.8. The overall model fit is significant (p = 0,000) and hence it can be concluded that

Coefficients[a]

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.	Collinearity Statistics	
		B	Std. Error	Beta			Tolerance	VIF
1	(Constant)	30,414	9,602		3,167	,002		
	Ratio earth roads	110,582	34,925	,322	3,166	,002	,681	1,468
	Road density [km/km2]	-4,899	3,332	-,141	-1,470	,144	,768	1,303
	WaterAccess	17,212	13,359	,145	1,288	,200	,554	1,805

a. Dependent Variable: U5MR [deaths per 1000 live births]

Figure 4.8: Multiple regression analysis for U5MR

the regression model fits the data better than the model with no independent variables. The R^2 is 0,466 which means that this model explains the U5MR for 46,6%. However, only the predicting variable of ratio of earth roads has a significant coefficient, where road density and water access are insignificant. This is often caused by multicollinearity, but this is excluded by the VIF and tolerance tests. It can be concluded from this model that the quality of roads highly impacts the U5MR, which confirms the effect of road infrastructure on U5MR, especially in combination with road density. Even though this variable is insignificant according to the multiple regression analysis, it can still be used for further analysis because the overall model fit is significant. This means that the model in total significantly explains the U5MR, even though not all separate coefficients are significant. Besides, singular linear regression of road density and U5MR turns out to be significant, so a a significant relation between the variables exists. The same goes for insignificant variable access to water and besides that, bad access to water is the number one cause for diarrhoea diseases which counts for a significant percentage of deaths of children under five (Hilderink & Lucas, 2008; Hughes, 2019). For these reasons, the regression model can be used as such and to generate the formula, the unstandardised coefficients from figure 4.8 must be used. This gives the following formula:

$$U5MR = 30,414 + 110,582 \cdot ERR - 4,899 \cdot RD + 17,212 \cdot WA \tag{4.4}$$

In which ERR is earth roads ratio, RD is road density and WA is water access. The latter variable is the ratio of people that do not have access to (safe) water, which is why the coefficient has a positive sign; more people without access to (safe) water increases the U5MR. The U5MR decreases with 4,899 with each unit of road density. With the confirmation from literature study about causality, this formula can be used as input for the system dynamics model in chapter 6.

4.6. Employment

This section aims to identify the relationship between road infrastructure and employment in Namibia. Employment differs from health and education analysis in the sense that there are no given job locations. First the relevant data is discussed and explained and secondly the spatial data analysis performed.

Employment overview

A solid measurement for employment in a country is the unemployment rate. According to Korsu & Wenglenski (2010), this measure is related to the accessibility of work for an individual; the risk of being unemployed highly depends on job accessibility. The International Labour Organization (ILO) defines being unemployed as all person of working age (>15 years old) without work during the reference period, currently available for work and seeking work (ILO, 2018). This is measured as follows:

$$UR(\%) = \frac{People unemployed}{Labour force} \cdot 100 \tag{4.5}$$

The eigth SDG says to "promote sustained, inclusive and sustainable economic growth, full and productive employment and decent work for all" and one of the indicators to measure this is the unemployment rate (United Nations, 2018c). Using unemployment as a measure is a widely used concept by researchers to test and compare the labour market among different countries or before and after a policy or reform (Dal Bianco et al., 2015; Decreuse & Maarek, 2015; Dosi et al., 2018). Table 4.8 below shows all constituencies that have an unemployment rate of 48% or higher.

Table 4.8: Constituencies in which the unemployment is 48% or higher

Region	**Constituency**	**Density [people/km^2]**	**Road density [km/km^2]**	**Unemployment rate**
Mashare	Kavango East	1,69	0,161	54%
Rundu Rural	Kavango East	7,04	0,266	53%
Rundu Urban	Kavango East	4228,73	5,467	63%
Kapako	Kavango West	13,24	0,065	57%
Musese	Kavango West	6,84	0,065	49%
Ncamagoro	Kavango West	1,53	0,194	52%
Opuwo Urban	Kunene	6,00	0,139	50%
Ohangwena M	Ohangwena	140,30	0,618	49%
Epukiro	Omaheke	0,56	0,074	49%
Otjinene	Omaheke	1,14	0,063	49%
Okalongo	Omusati	40,27	0,090	48%
Onesi	Omusati	27,60	0,188	55%
Otamanzi	Omusati	3,23	0,073	48%
Tsumkwe	Otjozondjupa	0,35	0,133	52%
Katima Muliro Urban	Zambezi	880,81	2,050	51%
Average of all constituencies		**2,54**	**0,140**	**37,6%**

First of all, mostly the Kavango regions perform bad on employment rates; both have three constituencies with an unemployment rate of higher than 48%. As for the road density, some of the constituencies have a low road density but definitely not all. At first sight, high unemployment rates do not seem to relate to road density. However, most of the population densities are above average, which implies that urban areas have a higher unemployment rate. Since population density is out of the scope of this research, the next subsection will only go in to depth on the relation between employment and road density.

Employment spatial data analysis

Figure 4.9 shows a scatter-plot of road density and the U5MR. Road density values of larger than 4 and U5MR of larger than 200 are excluded from the scatter-plot to get a better overview.

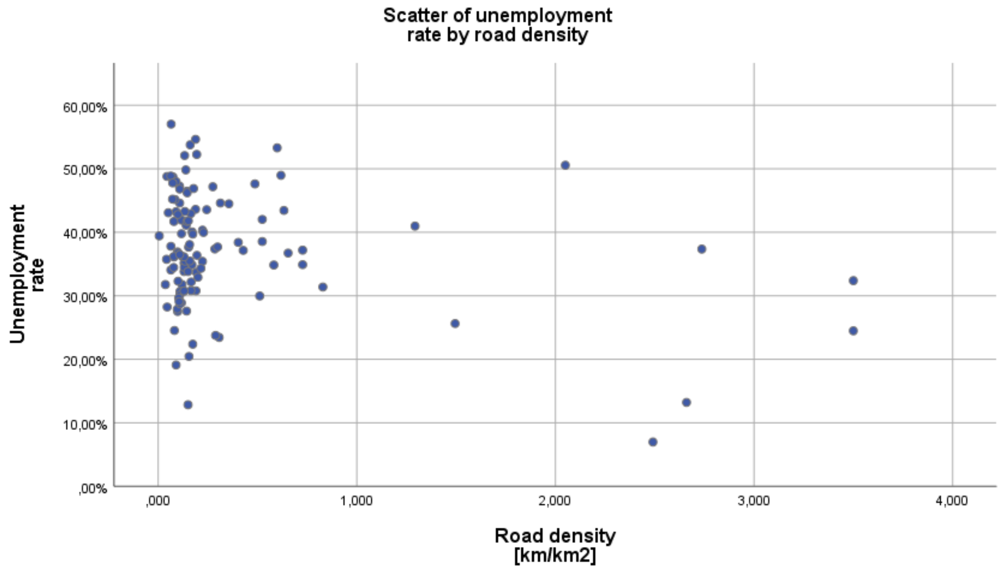


Figure 4.9: Scatter-plot of road density on the x-axis and the unemployment rate on the y-axis

The cases of unemployment are spread out over the full figure. Some high unemployment rates have high road density and vice versa. There seems to be less of coherence between the variables compared to education and health. To test the relation between road infrastructure and employment with multiple regression, other explaining variables than accessibility variables must be considered. Chapter 2.3.3 provided a framework for predicting variables for youth unemployment. None of the variables can be used for data analysis due to a lack of data. As for the accessibility, variables road density and earth roads ratio can be examined. Checking the unemployment data for outliers results in the elimination of the following constituencies: Katutura Central, Ondangwa Urban, Rundu Urban and Walvis Bay Urban. Figure B.7 in appendix B.3 shows the linear relations between road density and unemployment and earth roads ratio and unemployment. Linear regression between road density as a predictor for the unemployment rate gives a significant coefficient (B = -0,021, p = 0,034). This implies that a higher road density decreases the unemployment rate by 0,021 per unit road density. As for the earth road ratio, the significant is 0,258 (p = 0,005). Hence, both these variables comply to this assumption. The third, fourth and fifth assumptions are tested by looking at the scatter-plots in figure B.8. As for road density, most cases are on the right side of the vertical zero axis, but the cases on the left sides have a bigger deviation. The mean of all errors most probably adds up to more or less zero. The earth roads ratio plot shows half of the cases is left of the zero axis and half on the right. Hence, the assumption of zero conditional mean of errors is complied to. There is no pattern among the residuals which means it can be concluded that there is independence of errors. There is homoscedasticity in the errors, because there is constant variance of the errors with regards to the zero axis. The sixth assumption is the normal distribution of errors, which can be seen in figure B.9. The figure shows a normal distribution so it can be concluded that the errors follow a normal distribution. The last assumption is multicollinearity, which is complied to for both tolerance (> 0,1) and VIF (< 10). The result of the linear regression can be seen in figure 4.10.

Coefficients[a]

		Unstandardized Coefficients		Standardized Coefficients			Collinearity Statistics	
Model		B	Std. Error	Beta	t	Sig.	Tolerance	VIF
1	(Constant)	,314	,028		11,319	,000		
	EarthRoad	,212	,082	,234	2,587	,011	,980	1,021
	RoadDens	-,017	,010	-,164	-1,808	,073	,980	1,021

a. Dependent Variable: UnemploymentRate

Figure 4.10: Linear regression analysis of road density explaining unemployment rate

The overall model fit is significant and hence it can be concluded that the regression model fits the data better than the model without independent variables. The R^2 is 0,304 which means that this regression model explains the unemployment rate for 30,4%. Road density has a small and slightly insignificant impact on unemployment rate. The fact that the variable is insignificant is often caused by multicollinearity, but the variables are checked for this and do not have multicollinearity. It can be concluded that the quality of roads impacts the unemployment rate a lot more. Even though the road density comes out insignificant, it can still be used for further analysis because the overall model fit is significant. This means that the model in total significantly explains the unemployment rate, even though not all separate coefficients are significant. Besides, and because the singular linear relation between road density and unemployment is significant. The formula that can be derived from this output is:

$$UR = 0,314 - 0,017 \cdot RD + 0,212 \cdot ERR \tag{4.6}$$

In which UR is unemployment rate, RD road density and ERR earth roads ratio. It can be seen that road density has a very small impact on the unemployment rate; per unit increase in RD, the unemployment rate decreases with 0,021. Per unit increase in earth roads ratio, the unemployment rate increases with 0,212. This formula can be directly used in the SD model.

Linear relations The graphs as shown in the previous sections do not show a strong linear relation between school enrolment, U5MR, employment and road density. However, testing for different shapes and relations does not result in a significant relation. The identified relations do not serve as entirely valid and realistic relations, but they do indicate a relation which complies with literature. Therefore, it was still useful for the SD model, with the note that it should be considered to serve the purpose of facilitating *insights* in the dynamic system of road infrastructure and all factors and not a given and definite relation.

4.7. Interrelationships

According to literature, interrelationships between the factors might exist. This section investigates if the identified relations in literature exist in the available data on Namibia as well. Figure 4.11 shows the correlations between all factors and road density and population density. As can be seen in table 4.11, some of

Correlations

		PrimarySchoolAtt	U5MR	Uemployment
PrimarySchoolAtt	Pearson Correlation	1	-,185*	-,073
	Sig. (2-tailed)		,046	,434
	N	116	116	116
U5MR	Pearson Correlation	-,185*	1	,227*
	Sig. (2-tailed)	,046		,014
	N	116	116	116
Uemployment	Pearson Correlation	-,073	,227*	1
	Sig. (2-tailed)	,434	,014	
	N	116	116	116

*. Correlation is significant at the 0.05 level (2-tailed).

Figure 4.11: Correlations of education, health and employment with population density and road density

the variables have reciprocal correlations (so factors with each other). The significant correlations are indicated by one or two stars. The relevant and significant correlations that are within the scope of this research are as follows. Firstly, positive correlation exists between employment and health (0,227). This relation is not found to be of uniformly defined in literature; there is not much research on the coherence between these two variables and the existing researches are mostly focused on precarious employment which is not included in the data or suggestions for further research. Therefore, even though a correlation between employment and health is found, the relation is not taken into account in the model in chapter 6. Secondly, a positive correlation exists between health and education (-0,185), which is a defined relation in literature. The positive relation means that a better health usually goes hand in hand with a better education attendance rate. This relation is used in the SD model in chapter 6. The framework in figure 2.1 shows a relation between education and employment. However, in the Namibia data this relation does not exist; there is no significant correlation between the variables. Therefore, this relation is not modelled in the SD model.

4.8. Outcome data analysis

Not all relations of the original framework (figure 2.1) could be tested due to limited data availability. Besides, not all relations that could be tested were confirmed by the data. Figure 4.12 shows an overview of the outcome of the data analysis, showing all relations that were found in this chapter.

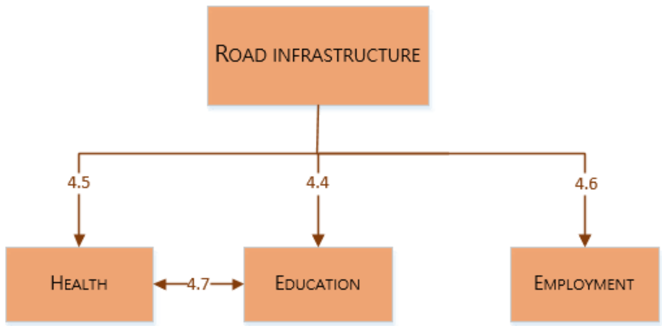


Figure 4.12: Relations identified in data analysis

4.9. Conclusion | Spatial data analysis

This section aimed to answer the fourth research question, which is briefly summarised in the box below. Besides, when looking at the scatter plots of education and health and road density, one can see that there are quite some constituencies with a low road density but good performance on one or both of these factors. Before performing the multiple regression analyses, a couple of assumptions had to be checked. One of these assumptions is that there should not be outliers. All the outliers were constituencies that are either urban with a high road density, or constituencies with an extraordinary high or low value for the tested variable (for instance Epupa for education enrolment). This makes sense, since these values do not represent the average or usual constituency and the effect on those is better tested with these constituencies excluded.

Figures D.1 and D.2 show the performance of all factors for each constituency. Interestingly enough, there are no constituencies that perform poorly on all factors. This could be explained by the political program of a constituency or the point of focus and choices of expenditures for certain factors. There are also a lot of external - geographically dependent - factors that positively or negatively affect only one of these factors in a constituency, such as drought, access to safe water, the availability and quality of teachers or doctors, or the extent of industrialisation or manufacturing business. Chapter 5 investigates possible explanations for different performance of constituencies with the same road density.

Figure 4.13 shows the overall performance of the regions for education, health, employment and tourism. The first column shows road density, the second shows share of 7 until 13 year old's that attend primary school. The number in the health column represents the U5MR [deaths per 1000 live births], the percentage in employment represents the unemployment rate and the number in tourism column is the number of tourists on a yearly basis. All constituency level values are weighted for surface (road density) or population (education, health and employment).

Region	Road density	Education	Child mortality	Unemployment
Erongo	0,165	0,913	43,6	0,303
Hardap	0,127	0,890	70,8	0,353
Karas	0,097	0,917	56,3	0,331
Kavango East	0,173	0,872	107,1	0,530
Kavango West	0,174	0,807	100,0	0,428
Khomas	0,338	0,897	38,4	0,294
Kunene	0,144	0,613	86,1	0,344
Ohangwena	0,150	0,898	70,0	0,427
Omaheke	0,105	0,774	62,3	0,400
Omusati	0,124	0,916	62,5	0,423
Oshana	0,169	0,914	60,0	0,369
Oshikoto	0,122	0,891	58,2	0,359
Otjozondjupa	0,150	0,823	56,1	0,373
Zambezi	0,144	0,888	106,3	0,382

Figure 4.13: Overall performance of each region for the four factors; red is bad performance and green good performance

One can see that the surface weighted values for road density are quite close to each other; they range from 0,097 to 0,338. Similar to the constituencies, there is no region that performs poorly on all factors. Hence, one cannot conclude to invest in road infrastructure in one particular constituency to improve on all facets.

RQ4: "What are the relations between road infrastructure, road safety, emissions, economic growth, education, health, employment and tourism in Namibia?"

Not all relations could be checked due to limited data availability. Figure 4.12 shows the identified relations of this chapter. These relations are discussed in the list below and are used as input of the SD model.

- **Roads and education**
  Road density influences the primary school enrolment together with the schools per surface and the materials of the walls. Not all three independent variables came out significant; road density remains insignificant. To avoid high insignificance and some reciprocal correlation, the schools per surface are taken out. It is logical that materials of the walls predicts the education enrolment a lot more, since that is a derivative of income level. However, together with findings in literature, it can be concluded that the higher the road density, the higher the primary school enrolment. Hence, education enrolment can be improved through a higher road density.

- **Roads and health**
  Besides road density, U5MR is influenced by the quality of road and the access to safe water. The water explains the U5MR for a large part, which is supported by literature. Water access mostly affects the U5MR through diseases such as diarrhoea. Hence, it is logical that this coefficient is large and significant. The earth road ratio also explains the U5MR, from which it can be concluded that the quality of road infrastructure matters for (the accessibility of) health (care). The road density is not found to be significant in the multiple regression analysis, but with findings from literature and it correlating with U5MR by itself, road density is still used as a predictor for the U5MR, but just with a very small impact. Hence, a better road infrastructure slightly decreases the U5MR.

- **Roads and employment**
  There is no data available other than road density and road quality which can explain the unemployment rate in Namibia. Quality of roads is the biggest predictor of unemployment rate. Road density came out insignificant, but with confirmation from the literature study and the fact that singular regression between road density and unemployment does come out significant, road density can still be used as independent variable for the unemployment.

- **Health and employment?**
  A positive correlation exists between health and education, which is a defined relation in literature. The positive relation means that a better health usually goes hand in hand with a better education attendance rate and the other way around.

It is clear that for all factors, road density is not the largest predicting variable. Each factor has its own drivers and main causes, but data analysis does confirm that there is a small relation between road density and education, health and employment.

5

Explanations behind the data

This chapter aims to get more detailed insights in the actual situation of constituencies in Namibia. The outcomes of both literature and data analysis are generalised and mostly based on means, where the scatter plots in chapter 4 show that one value for road density can have discrepant performances on the factors. Also, some constituencies score very well on one factor but poorly on another. This chapter attempts to understand these different outcomes by investigating two constituencies in depth. This is done by choosing different constituencies with a similar, low road density of which three perform well and one that performs poorly on the factors. With these insights it answers the fifth research question: "What are possible underlying explanations for constituencies with similar road densities and discrepant performances on the factors?". The focus is only on education, health and employment, since there is no data on constituency level for tourism.

5.1. Choice of constituencies

It is ideal to investigate different constituencies with poor road density: constituencies with good performance and with poor performance. Figure D.1 and figure D.2 show the overall performance of all constituencies in terms of road density, education attendance (never attended school rate), child mortality (U5MR, in deaths per 1000 live births) and unemployment (unemployment rate). Figure 5.1 shows the ten worst performing constituencies in terms of road density, ranging from 0,005 to 0,065 kilometre road per square kilometre. The colour scale is still relative to the other 111 constituencies.

Constituency	Road density	Education	Child mortality	Unemployment
Okatyali	0,005	0,948	28,0	0,394
Ompundja	0,036	0,939	25,0	0,318
Otjombinde	0,042	0,746	48,8	0,357
!Nami=Nus	0,045	0,937	39,1	0,282
Onyaanya	0,051	0,944	48,2	0,431
Otjinene	0,063	0,825	62,2	0,489
Okankolo	0,064	0,843	54,6	0,378
Engodi	0,064	0,808	59,1	0,341
Kapako	0,065	0,791	84,3	0,570
Musese	0,065	0,800	187,0	0,488

Figure 5.1: Ten lowest constituencies in terms of road density

Good performance The first two constituencies Okatyali and Ompundja have a low road density but good performance on education and health. However, both these constituencies have little inhabitants (3187 and 4659 respectively) and therefore it is more difficult to consider the numbers in the table as normative. !Nami=Nus also has little road density and good performance (also on employment) and more inhabitants (13859) and therefore all three constituencies are investigated in this chapter.

Poor performance There is one constituency outstanding in terms of poor performance in terms of health: Musese. This is not the constituency with the lowest road density, but these constituencies are quite close to each other in terms of road density value. Besides, 18% in this constituency did not attend school which is also quite a bad score and 49% of the economically active population is unemployed. This constituency has 10011 inhabitants. It serves as a suitable constituency to get more insights in the road density and the education and health outcomes.

5.2. Low road density - good performance

This section discusses the three constituencies with low road density but good performance on health, education and employment. The main sources used for this analysis are the regional profiles published by NSA, shapefiles of constituency borders and the road network in QGIS and Google maps. Although, there is a small positive relation between road density and health and education, these constituencies do not serve as an example of that. This section aims to find out if there is a underlying reason for the deviancy of these constituencies by looking at population distribution over the surface, the proportion of people living in urban and rural areas, the distribution of the road infrastructure over the surface and the supply of education and health facilities.

5.2.1. Okatyali

First of all, Okatyali constituency only has 3 kilometres of roads according to the used shapefile. This explains the extremely low road density (0,005). However, when looking at the constituency on satellite maps, more roads are visible. Figure 5.2 shows a zoomed in satellite map with major roads as indicated on the maps (white) and the road indicated by the shapefile (red). The black lines are the boundaries of the constituencies. The smaller roads are not indicated as they are not indicated by Google maps and difficult to identify by satellite. According to the regional profile of Oshana, there is no urban locality in Okatyali (NSA, 2019). Google maps shows that people are spread out over a part of the constituency, mostly living on small settlements. About half of the constituency is uninhabitable due to salt pans and other natural phenomena that make the land not suitable to live. The regional profile reports there is not much income due to farming, so these settlements are probably small villages and not farms. Most of these settlements are located along the road that goes from north to south as can be seen in figure 5.2. There are three educational facilities and zero health facilities in the constituency, but Okatyali constituency is relatively small (558 km^2) which means that people can easily cross borders of constituency to go to other facilities, of where there are a lot in the surrounding constituencies.

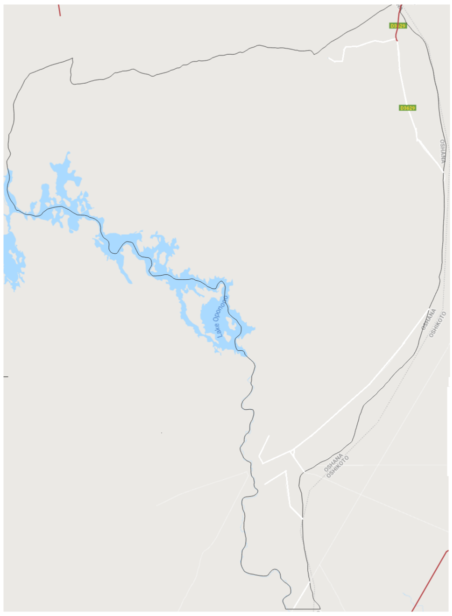


Figure 5.2: Roads in Okatyali constituency

All in all, the two biggest explaining factors for the good performance of this constituency with low road density are the lack of indicated roads in the shapefile and the fact that half of the constituency is uninhabited. However, even with these two reasons taken into account, the road density would be quite low. Hence, it is not entirely unambiguously why this constituency performs good with a very low road density.

5.2.2. Ompundja

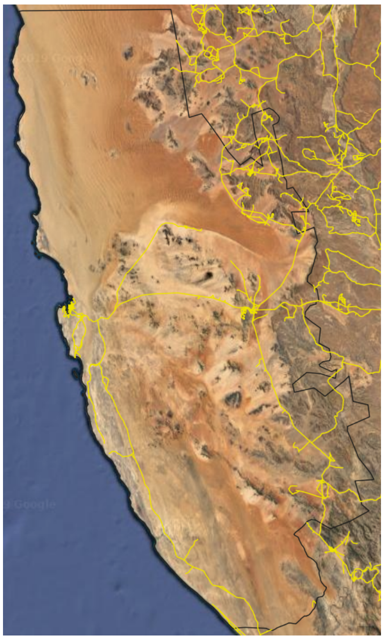
Ompundja has 4659 inhabitants which is a small population. There is no urban area, so most people live spread out over the constituency, although there Ompundja is a town where one can see some settlements on the satellite maps. The constituency has 17 kilometres of road according to the used shapefile. Google maps confirms this, but also only shows the bigger roads. On satellite map one can see many more smaller roads, probably gravel or earth roads. The constituency is 466 km^2, which is relatively small. This possible means that people can easily reach other constituencies and their facilities too. Ompundja has nine education facilities spread out over the constituency, which implies that everyone has relatively good access to education in terms of distance. There are no health facilities in the constituency itself, but there are some in the surrounding constituencies. Lastly, the town Ompundja lies on a twenty minutes drive from Oshakati and fourty minute drive from Ondangwa, which are quite big towns with a lot of facilities. The biggest highway in Namibia - the B1 - goes through these towns.

There is not one fully explaining reason for the low road density and good performance on the factors. However, it is most probably the position of the constituency that makes that it performs well on the factors. Two big towns lie close to this constituency: Oshakati and Ondangwa.

5.2.3. !Nami=Nus

This constituency mainly consists of desert; figure 5.3 shows a satellite map of the constituency in which the constituency borders are black and the roads yellow. These parts are uninhabited and not suitable for civilisation. This explains the very low road density (0,045). !Nami=Nus has 13859 inhabitants of which 12537 live in the city Lüderitz. This means that only 1322 people live outside of Lüderitz and most of these people mainly live in Aus, another town in the constituency. Lüderitz has four education facilities in town and two health facilities and Aus one education facility and two health facilities. Hence, most people live very close to facilities and in urban area and have good access to facilities. Figure 3.3 shows an overview of the different land types in the country and a lot of these land types make a place uninhabitable. Therefore, it is likely that there are more constituencies like !Nami=Nus that have a large surface but only small parts are inhabited, which gives a very low road density but possibly good performance on factors.

Figure 5.3: !Nami=Nus satellite map

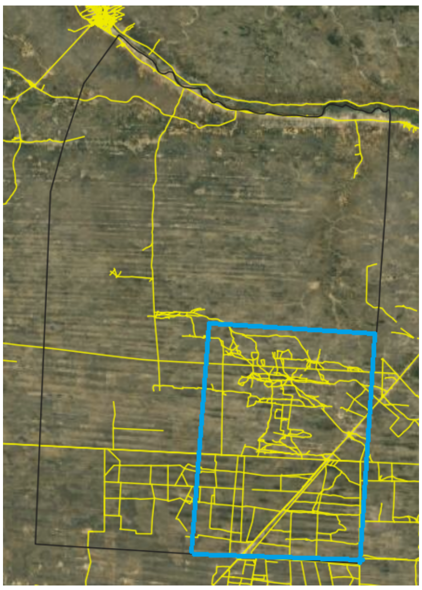


The surface of !Nami=Nus is large, but a big part of the area is uninhabited due to the desert which explains the low road density. Besides, most, if not all, of the population lives in urban areas and has good access to basic facilities such as schools and health care facilities. This explains the good performance on health and education.

5.3. Low road density - poor performance: Musese

Musese constituency has 10011 inhabitants and 2195 square kilometres surface. Musese used to belong to the much bigger constituency Kahenge and therefore there is little information available on Musese itself; the regional profile of Kavango does not distinguish Musese yet. Figure 5.4 shows the little roads that Musese contains in yellow and the borders of the constituencies in blue. The black lines are the borders of old constituency Kahenge. There are 22 education facilities, which are quite spread out over the constituency. Still, 18% of the population does not attend school, which can be caused by the lack of infrastructure or the poor quality of the infrastructure. The same goes for health; there are four facilities in the constituency but the U5MR is 187 which is far above the Namibian average. Another health related aspect is the fact that the safe water access in the Kahenge constituency decreased dramatically; in 2001 91% had safe water and in 2011 only 68%. This could explain the high U5MR; safe water is of great importance for development, poverty reduction and health (Prüss-Üstün et al., 2011). An explanation for the drastic reduction of safe water access could be the lack of rain and therefore ongoing droughts Namibia has been experiencing in 2001 and 2002 (Masih et al., 2014).

Figure 5.4: Musese constituency



5.4. Conclusion | Explanations behind the data

RQ5: "What are possible underlying explanations for constituencies with similar road densities and discrepant performances on the factors?"

There is not one major reason for discrepancy in performance for similar road densities. However, one can still conclude that for most Namibian constituencies, a (large) part of it is uninhabitable and does not have roads there. This makes the road density low but most people live in bigger tows with roads and facilities. A second reason is that there are big towns on a foreseeable distance hence very accessible for population of the neighbouring constituency. Lastly, the shapefile can contain mistakes. All in all, there is not a simple way of accounting for discrepancy in performance in performance of constituencies with similar road densities. These different explanations indicate that road density is not a comprehensive and strong indicator of road infrastructure. Unless used tactfully and logical, road density is not a meaningful way of measuring or assessing road network. An increase in road density could - in theory - imply constructing new roads anywhere within a constituency and performance on factors would go up (according to the data analysis). Therefore, one should bear in mind that, when using road density as a metric, attention has to be paid on where to construct roads and how much. Hence, if road density is used as a metric to assess road infrastructure, it should be used carefully and well-thought-out. To do so, future scenarios are identified in the next section that take this into account.

6

Model development

Every combination of uncertain input factors can lead to a different outcome of the future. In this chapter, the method and the developed model to assess the impact of road infrastructure investments in Namibia are discussed. As established in previous chapters, the model will be developed from a System Dynamics perspective. Section 6.1 explains the method of system dynamics and how to use it and section 6.2 describes what multi-scale modelling is and how to use it in SD. The model components of the basic model and the extended model are explained in section 6.3 and 6.4 respectively. Section 6.5 At the end of this chapter, the sixth research question: "What model is developed to investigate the effects between road infrastructure, economic growth, road safety, emissions, education, health, employment and tourism in Namibia in future scenarios?" is answered.

6.1. System Dynamics

The goal of the System Dynamics model is to evaluate the effects of improved road infrastructure on factors health, education, employment and tourism in Namibia. System Dynamics is an aggregated approach and therefore the level of detail remains quite low. This means that some variables are based on assumptions.

6.1.1. 'Building blocks'

System Dynamics allows for estimating effects of a policy measure on a system - in particular a country - and gives insight in (long term) results and effects of a policy measure such as road infrastructure changes on a system or country. Therefore, this modelling method is very suitable for this study. The paragraphs below discuss the major building blocks of SD as used in this research.

System elements and model variables “Systems consist of elements and relations between (some of) these elements” (Pruyt, 2013). A model attempts to represent a simplified version of a system. To do so, variables and links between (some of) the variables are made. In SD modelling, different types of variables are used: (i) stocks, which are integral equations of flow. Generally change slowly and therefore they act as delays or buffers in systems (Meadows, 2008). (ii) Flows and auxiliaries, which are equations of other variables and parameters and constants. There are two types of flows: inflows and outflows. Depending on the flow being positive or negative, it increases or deceases the content of the reservoir. Hereby, they regulate the states of stock variables. Flow variables are the variables that can be targeted by strategies to improve stock variables in problematic condition or state. And (iii) parameters and constants,w hich assume (constant) values over a simulation run.

Causal links and structures A causal link represents a relation between two variables. A plus or minus symbol indicates whether the independent variable has a positive or negative impact on the dependent variable, respectively. This symbol is called the link polarity. By having direct causal relations, "SD could be used to explore the interaction between the (assumed) structure and the dynamically complex behavior of these issues, for example to gain insights, and from these insights, transform structures to steer the system towards more desirable behaviors" (Pruyt, 2013).

Feedback loops A feedback loop is a representation of a feedback structure in a SD model, consisting of causal links from one variable connecting back to that same variable, after connecting to other variables

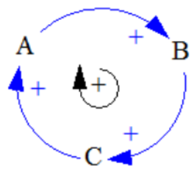


Figure 6.1: Positive feedback loop

(Sterman, 2000). Figure 6.1 shows an example of a feedback loop. A feedback loop can be positive or negative, indicated by a sign + or - symbol in a circle of an arrow (like in figure 6.1). The polarity of the loop depends on the effect that an initial increase in variable A has on variable B.

6.1.2. Diagrams

Depending on the purpose of the model, a certain diagram is used. This study uses a causal loop diagram to communicate feedback loop systems and a stock-flow diagram for the actual model.

Causal Loop Diagram This research has a high focus on the relationships among variables and the overall structure of the system and therefore causal loop diagrams (CLDs) will be used. Most transportation studies in SD are based on this technique. CLDs consist of variables and causal links linking these variables and they can generate valuable insights in the possible behaviour the system entails (Gruel & Stanford, 2016). Once the CLD is assembled, one can identify feedback loops. These loops often play a big role in the overall behaviour of the model which makes it important to identify them. The feedback loop in the framework of this study (figure 2.1) is represented by the bidirectional relation between road infrastructure and economic growth. The dashed line in the framework indicates the uncertainty of the relationship. Figure 6.2 shows the causal loop diagram of this study, with the uncertain relations indicated by dashed lines. Two models are developed in this chapter; without the two uncertainties and one with. Uncertainty and how to handle it is explained in section 6.4.

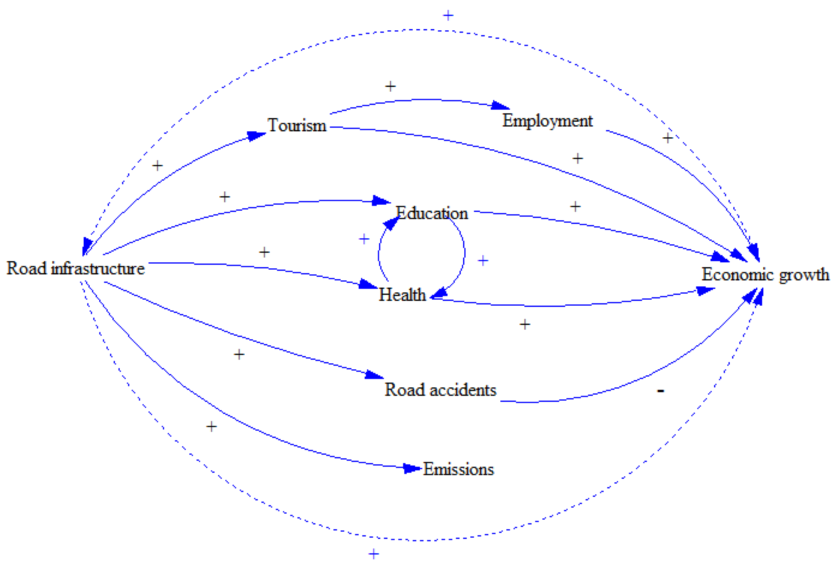


Figure 6.2: Causal loop diagram

The CLDs is based on the theoretical framework as shown in figure 2.1. The relations between two variables that do not have a relation as came forward in the data analysis are deleted from the framework. The relations between variables that do have a correlation according to the data analysis are shown in the CLD together with relations which cannot be tested in the data analysis due to a lack of data but which are confirmed by literature. It must be noted that the model as described below is on a highly aggregate level. The scope of this research is very broad and to include all variables and relations between variables in the model, a lot of assumption have to be made and relations have to be simplified. The assumptions and simplifications are explained per sub-model in the sections below.

Stock-flow diagram Stock-flow diagrams consist of stock variables, flow variables, auxiliary variables, parameters and constants, causal links between variables and causal links with delays. Figure 6.3 shows an example of a stock-flow diagram The stock variable accumulates flows over time. During simulation, the stock

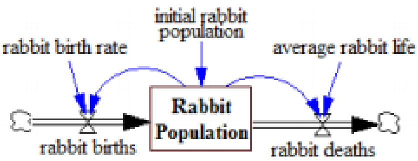


Figure 6.3: An example of a stock-flow diagram (Pruyt, 2013)

is increased by its inflow rates (rabbit births in figure) and decreased by outflow rates (rabbit deaths in figure). The basis of the model of this study consists of stock-flow structures. Each factor or variable discussed before is discussed in section 6.3 as model components.

6.2. Multi-scale approach in SD

Incorporating space into system dynamics is not something new and is definitely possible (Bendor & Kaza, 2012). Examples of spatial problems modelled in SD are zonal models such as chaotic behaviour in a two-zoned city (Mosekilde et al., 1988), the movement of foot and mouth disease between zones (Rich, 2008) and land-use transportation interactions (Pfaffenbichler et al., 2010). These examples all attempt to spatially disaggregate the area. However, the use of multiple scales within one SD model is something new and therefore there is no research on this topic available (yet). As explained above, the census data are available on constituency level. These constituency data can be taken to a regional level and thereafter to a national level. Usually, one would have to make a separate function or sub-model for each constituency and region. With the newly discovered modelling technique that allows multi-scale modelling in SD models, only one variable or sub-model is needed for all constituencies or for all regions. The advantages of multi-scale modelling in SD are as follows (Pruyt, 2019):

- Allows for different geo-spatial scales in the same model architecture
- Allows for mixing and matching of different logics, such as Agent-Based Modelling (ABM), SD and markets.
- Allows for different levels of decision-making. It provides a focus for each on their level (strategic, tactic and operational).
- Gives the most lean representation of a system by the ability to use a simplified model.

The first, third and fourth advantages are of benefit in this study. As came forward, data is found on different levels; mostly on constituency level and region level. With multi-scale modelling, these different scales can be used within one model. This leads to the possibility of decision-making on different levels, for instance education, health and employment wise data is available on constituency level and hence decisions can be made on that level. For tourism it makes sense to make regional and country policy and decisions. This can all be done based on the same model.

The general model incorporates multi-scale modelling with the use of subscripts. Subscripting allows for the simultaneous simulation of a generic model for multiple entities; in this case constituencies. This means that all constituencies are now represented within one variable. Each entity (constituency) can be initialised with different values or processes. The subscripts can easily be filled by referring to an excel file and can also be assigned to their accompanying regions. Appendix C gives a step-wise overview of creating and using subscripts. By doing this, the model does not need 121 variables (one for each constituency) for all factors, road densities, etc. The output can be generated for each constituency separately. Furthermore, this research is focused on investigating the impact of road infrastructure on socio-economic factors and therefore the model assesses the absolute growth or decline caused by road infrastructure.

6.2.1. Model set-up

The aim of the model is to show the relative growth caused by improved road infrastructure. Therefore, equations (4.2) and (4.4) are not directly used as such, but the change that one unit road density causes in each factor. The model uses months as a unit of time to account for duration of road construction and it goes from 2011 to 2021. Hence, there are 10 * 12 = 120 units of time in model run. Besides, it is of great importance to understand that road density is not a meaningful way of measuring road infrastructure on itself, because just an increase in road density does not automatically mean that a constituency's performance on factors will improve. To have an effect, the extra roads should be located tactfully and logical, for instance to connect one village without facilities to a village with facilities or just to a small school. For the scenarios it is implied that the roads are placed as such. If properly used, road density can be a useful metric. Chapter 7 identifies KPIs and scenarios that are implemented in the model and within the scenarios road investment and placement is chosen carefully.

6.3. Model components basic model

This section elaborates on all the model components, being the road infrastructure, economic growth, education, health, tourism, road safety and emissions. Hence, each variable as shown in figure 6.2 is considered a sub-model. The sub-models of road safety, emissions, education, tourism, health and employment give an explanation on how the road infrastructure influences the factor of subject and how (some of) the factors affect economic growth. For most factors, it applies that road infrastructure will not influence them directly; some time will pass before the effect works. Therefore, Vensim's SMOOTH function is used in which the effect is spread over a defined time. The SMOOTH functions use a time of 12 months.

6.3.1. Road infrastructure

As can be seen in table 4.4, the proportion of salt roads is negligible for almost all regions and therefore not taken into account in the model. The model distinguishes bitumen, gravel and earth roads. Either new roads of a specific type are constructed or roads are upgraded. Upgrades can be from earth to gravel or directly to bitumen and from gravel to bitumen.

6.3.2. Economic Growth

The economic growth is represented as a stock of the GDP. The initial value of the GDP stock is N$47.358 (National Planning Commission, 2017). Most of the factors are measured and computed either on constituency or region level. The GDP is measured on country level and therefore the factors need to be summed and in some cases averaged to insert the impact of that factor on the GDP.

6.3.3. Education

Both the literature study as the data analysis acknowledge a positive relation between road infrastructure and school attendance. Equation (4.3) gives the formula to determine the primary school enrolment rate. The relative change that one unit of road density changes in primary school enrolment is 0,012. This is very little, so the model most probably does not show a large improvement by adding roads. The relation between primary school enrolment and the GDP is not uniformly discussed and determined, since some researchers mainly focus on the effect of improved education quality on GDP Castelló-Climent & Hidalgo-Cabrillana (2012); Hanushek & Wößmann (2007) and the effect is highly context dependent. Cooray (2010) researched the role of education in economic growth in 46 developing countries in Southern America, Asia and Africa and concluded that 1% increase in primary school enrolment leads to a 0,16% increase in per capita income. The per capita income is the total GDP divided by the number of people. Hence, this 0,16% increase per 1% PSE increase can be directly translated to the GDP.

6.3.4. Health

Chapter 4 showed the relative influence that road density has on U5MR. This can be directly inserted in the model, hence for each unit of road density increase, the U5MR decreases by 4,899. Besides, the ratio of road type is also of influence. The larger the ratio of earth roads (worst quality) relative to gravel and bitumen, the higher the U5MR. This implies that the U5MR can be improved by having less earth roads. The contribution of health to economic growth is acknowledged in the literature study. Bloom et al. (2004) constructed a panel of countries to observe the effect of health on the GDP. They conclude that one year increase in life expectancy leads to an increase of 4% of the GDP. Since they used a panel of countries, this general outcome can be used for the model. The fact that they used a panel means the outcome is not highly context dependent and the real magnitude of the relation for Namibia probably differs, but this is a solid assumption for the relation. Life expectancy and U5MR have a high coherence in Namibia; the highest share of deaths is by far in the 0-4 age group (NSA, 2014). This report indicates life expectancy on regional level and the correlation between the weighted average of all U5MRs of constituencies belonging to one region and the life expectancy is -0,867, significant on 0,01 level. For the increase of one unit of U5MR (so one death per 1000 live births), the life expectancy decreases by 0,19. Hence, a decrease in U5MR due to more or better roads would increase life expectancy which positively affects the GDP.

6.3.5. Employment

The formula for the effect of road density on employment can be taken from the statistical analysis in chapter 4. For each unit of road density increase, unemployment decreases with 0,017. Besides, the road quality influences the unemployment rate; worse quality of roads results in higher unemployment rates. This implies that if the ratio decreases, so if quality increases, the unemployment would decrease as well. As for the effect of a lower unemployment rate on GDP, Frenkel & Ros (2006) found that on average, a decrease of one unit in unemployment rate, ensures a 4,2% growth in GDP. According to Ministry of Environment and Tourism (2015), the relation between tourism and employment is significant in Namibia. The ministry reports a growth in the number of tourists arriving each year and in the number of jobs generated by tourism. These two factors grow simultaneously; the growth in the number of tourists generates more jobs. For each tourist arriving 0,07 jobs are generated. By dividing the extra jobs generated by economically active labour, it gets clear how much extra employment there will be. This is added to the decrease in unemployment rate in the model.

6.3.6. Tourism

The tourism sub-model attempts to capture the relation between road infrastructure and tourism. The number of tourists in Namibia in 2017 was 1,499,000 (The World Bank, 2017a). There is no information on tourism available in the census data from 2011. Ideally data would be available through regional profiles or annual reports from the ministry of tourism. Some annual reports discuss places mostly visited by tourists. An overview of which proportion of all tourists which places (some tourists visit multiple places so it does not add up to 100%) can be found in table 6.1. The information is mostly derived from Millennium Challenge Account Namibia (2013). Most of these attractions are not located in one constituency, but spread out over multiple constituencies. Therefore, one cannot obtain the number of tourists per constituency. This is where one of the benefits of multi-scale modelling comes in; one can take the average weighted density for population and roads from all constituencies belonging to one region. Table 6.2 shows the total number of tourists per *region* of one year, based on 2017 data on total tourists per year. It contains the fourteen regions, which would be a very small sample size to perform statistical tests. Therefore, this source of information cannot be used for further statistical analysis. There is no suitable data on tourism available to perform tests that can really determine a relation between tourism and roads in Namibia. Besides, tourism in Namibia is mostly dependent on existing (natural and cultural) attractions. There will still most likely be a positive effect of more or better road infrastructure from and to these attractions, but that is not as much constituency dependent. As input for the SD-model, a relation found in literature will be used. Since there is no tourism data on constituency level available, findings in literature are used in the SD model for this sub-model. The tourism related numbers as explained in chapter 3.2.2 are Namibia specific and acknowledge the significant relation between tourism and the GDP in Namibia. However, the numbers are not at all related to road infrastructure. Therefore, these numbers cannot directly be used in the model and complementary information is needed.

Khadaroo & Seetanah (2007) found a positive relation between transport capital stock and tourism arrivals; a coefficient of 0,36 implying that a 10% increase in the stock of transport capital yields a 3,6% increase in arrivals in the island. Since they use the stock of transport capital as a variable instead of something road and length or density related, this cannot be used for the SD model. Another research that found a quantitative positive significant relation between the two variables in Malaysia is done by Kosnan et al. (2013). They found that for a 10% increase in kilometres of road, the international tourism increases by 7% and that for a 10% increase in paved roads (bitumen), international tourism increases by 1,9%. These values are case-study specific, however characteristics such as a variety of ethnicity, cultures and religions and tourism growth and GDP growth are similar to this Namibia case-study. As discussed before, the number of tourists in Namibia is known per region and not on constituency level, where all road data is on constituency level. In order to make causal relations in the SD model, the subscript level must be the same. Therefore, the road data needs

Table 6.1: Tourism attractions, the region the attraction is located in and proportion of tourists visiting this attraction

Attraction	Region	Perc.
Windhoek	Khomas	55,6%
Swakopmund	Erongo	30,3%
Walvis Bay	Erongo	25,2%
Oshakati and Area	Oshana	23,0%
Etosha	Kunene	22,1%
Sossusvlei	Hardap	18,1%
Fish River Canyon	Karas	11,4%
Damaraland	Kunene	10,2%
Namib Naukluft Park	Hardap	9,8%
Luderitz	Karas	7,2%
Kavango Region	Kavango	7,0%
Caprivi National Park	Zambezi	7,0%
Spitzkoppe	Erongo	6,7%
Waterberg park	Otjozundjupa	6,0%
Brandberg	Erongo	5,0%
Caprivi region	Zambezi	5,0%
Skeleton Coast Park	Kunene	5,0%
Kaokoland	Kunene	4,0%

Table 6.2: Number of tourists for each region per year

Region	Population density [people/km]	Road density [km/km2]	Number of tourists
Erongo	2,370	0,165	1007328
Hardap	0,725	0,127	418221
Karas	0,480	0,097	278814
Kavango East	5,648	0,173	52465
Kavango West	3,386	0,174	52465
Khomas	9,260	0,338	833444
Kunene	0,751	0,144	619087
Ohangwena	23,127	0,150	0
Omaheke	0,841	0,105	0
Omusati	9,140	0,124	0
Oshana	20,408	0,169	344770
Oshikoto	4,705	0,122	0
Otjozondjupa	1,367	0,150	89940
Zambezi	6,176	0,144	179880

to be generalised to the level of regions in the tourism sub-model. This can be done by referring to a matrix in Excel which indicates which constituencies belong to which region. With this information and a summation over all belonging constituencies, the road length is calculated for each region. This road length is used as input to determine the growth of tourism caused by better or more road infrastructure.

According to the National Planning Commission (2017), tourism accounted for 9,89% of the GDP in 2016. The number of tourists in 2017 totalled 1,499.000. The contribution per tourist to the GDP would then be 0,0989/1.499.000 = 6,5 * 10^{-8}.

6.3.7. Road Safety

This sub-model only consists of the relation from road infrastructure in chapter 2 shows that the effect of the road infrastructure on road safety is not uniformly determined. Better roads mainly lead to a better road safety but more roads generally to worse road safety. The numbers on the increase in road length and the fatalities and injuries given in chapter 4.3 do not reflect a coherent relation between more roads and more injuries and fatalities; the number of fatalities and injuries seems to increase independently from the changes in the road infrastructure. Therefore, the model assumes a growth of 6,4333 * 10^{-3} per year for injuries and 4,56667 * 10^{-3}) per year for fatalities; the averages of the increase of the fatalities and injuries as shown in table 3.6. According to NRSC (2015), road fatalities and injuries cost the government 3% of the GDP per annum (as of 2015). Since the unit of time in the model is month, 3% should be divided by 12 months, which equals 0,25%. There is no reference value of a different year available and therefore this number is divided by road crashes. The number of fatalities and injuries together equalled to 8076 in 2015 (table 3.6). The relation from road injuries and fatalities to GDP is therefore - 0,0025/8076 = - 3,096 * 10^{-7} times number of road injuries and fatalities.

One of the findings of the literature study in chapter 2 on road safety is that road safety is dependent on the type of road infrastructure. For instance, gravel significantly reduces allowed and possible speed compared to bitumen. Safety is either reduced because of higher speeds and hence higher risk of accidents or increased by a better condition of the road thus a lower chance of accidents (Figueroa et al., 2013). According to Cloete (2018), the most significant causes of road accidents were caused by tyre bursts and stray animals on road reserves. Especially tyre bursts most likely to happen on poor quality roads, which implies that bitumen road material slightly increases safety. Therefore, this in included in the injuries and fatalities rate by a look-up function. The bitumen ratio (initial value 0,173) is the input of the increase in injuries and fatalities.

Lastly, road safety appeared high up the agenda of the Namibian government and different institutions. Therefore, it is likely that they will try to enhance road safety and besides improving the quality of the roads, they could have campaigns to raise awareness about the high number of crashes, have more (regular) speed and alcohol controls or make sure there is a larger space besides the roads free from animals and people. This is taken into account in the model as a variable of which the value 1 means the situation as it is now and the more the government invests in increasing or attempts to increase the road safety, the lower the number. This variable directly impacts the growth of crashes.

6.3.8. Emissions

The literature study introduced the emissions caused by road construction, maintenance, materials for construction and the extra vehicle movements as a result of more or better road infrastructure. However, it is difficult how much more extra vehicle movements a road is going to generate in Namibia and therefore this is not taken into account. The used effect consists of emissions caused by the used material, the construction and the maintenance of the road. In the model, it is about the *extra* roads when looking at emissions; hence existing roads are not taken into account in terms of emissions. For this research only the CO_2 emissions are taken into account. Figure 6.4 shows an overview of the tonnage CO_2 per kilometre. The emission depends on the type of road, distinguishing expressway, national road, provincial road, rural road (gravel or Double Bituminous Surface Treatment (DBST)) (Deng et al., 2010). The expressway indicates a modern and high

	Expressway	National Road	Provincial Road	Rural Road - Gravel	Rural Road - DBST
Emission (t CO2 eq. /km)	**3234**	**794**	**207**	**90**	**103**
Factor equivalent to Expressway	100	24.5	6.4	2.8	3.2

Figure 6.4: GHG emissions of various road categories (Deng et al., 2010)

quality road with multiple lanes. Namibia does not have these roads and most likely they will not be built in the near future, because there is not that much traffic and the construction and maintenance is very costly. The roads indicated as 'bitumen' in this study take the value of the national road, since all paved roads are national roads and the gravel roads take the value of rural road - gravel. There is no value for earth graded roads and therefore the (relatively low) emissions of the earth graded roads is not taken into account. The aim of this report is to design a toolkit for developing countries and the calculations are made with the "Changer" tool developed by the International Road Federation (IRF). These two things make that the computations of this research can be used as a solid assumption for the model.

6.4. Model components - extended model with uncertainties

The major feedback loop in this study is the bidirectional relation between road infrastructure and economic growth. The relation from road infrastructure to economic growth is partly explained by the underlying relations as can be seen in the framework, but the size of the part that is explained by these variables remains unknown. Therefore, this is seen as an *uncertain* relation. The same goes for the effect of economic growth on road infrastructure; as discussed in chapter 2.2, there is no uniform definition of the relation and it is highly dependent on context. For this reason, this relation also needs to be modelled as uncertain. With the help of literature and modelling techniques such as sensitivity analyses, these uncertainties can be taken into account. However, the relations remain uncertain. The extended model includes the same model components and its relations as the basic model, but two uncertain relations are added. Uncertainty can be defined as "the entire set of beliefs or doubts that stems from our limited knowledge of the past and the present (esp. uncertainty due to a lack of knowledge) and our inability to predict future events, outcomes and consequences (esp. uncertainty due to variability)" (van Asselt, 2000).

According to Pruyt (2007), a common way of dealing with uncertainties in SD is to explore the uncertainties (by means of sensitivity analyses) to reduce some extent of the uncertainty and accept the irreducible uncertainties. However, one must take these irreducible uncertainties into account when interpreting the results and design robust policies and systems. Sensitivity analysis is one of the tools that SD software Vensim offers. It performs repeated simulations in which the model parameters are changed for each simulation. This can be very helpful in understanding the behavioural boundaries of a model and testing the robustness of model-based policies (Vensim, 2019).

6.4.1. Road infrastructure on economic growth

As came forward in chapter 2.2, the relation between transport infrastructure and economic growth is widely acknowledged. There is a shift in the economic approach of this relation towards the more broad consequences of transport infrastructure such as underlying socio-economic factors. More specifically, the effect of *road* infrastructure on economic growth is established by different researchers (Calderon, 2009; Elburz et al., 2017; Melo et al., 2013). Pradhan & Bagchi (2013) researched the effect of transportation infrastructure on economic growth in India. One of the conclusions is that an increase of 1 in the road length increases the GDP with 2,84. The most uncertain aspect on this relation is the extent to which road safety, emissions, health, education, employment and tourism explain the relation. The part of the relation of these variables can - theoretically - be 0% to 100%. This is modelled by using the maximum impact that road infrastructure might have on economic growth and have the relation vary between 0 and 2,84. Figure 6.5 shows the sensitivity graph of the magnitude of the effect of road length on GDP.

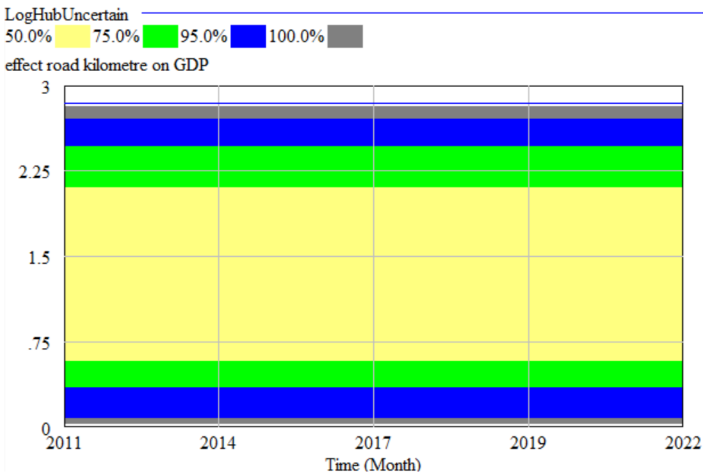


Figure 6.5: Sensitivity graph of the effect of road infrastructure on GDP

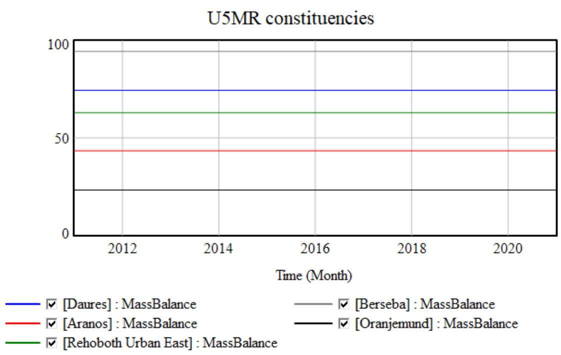
6.4.2. Economic growth on road infrastructure

The effect that economic growth has on road infrastructure is described and discussed in chapter 2.2. It got clear that the relation is uncertain and this is handled in the same way as the effect of road infrastructure on economic growth. Pradhan & Bagchi (2013) found a positive effect of economic growth on the road development in India. For an increase of 1% in the GDP, 2,85 kilometres road are added. However, this relation is highly context and decision-making dependent. Therefore, the relation is modelled by using the maximum impact that economic growth might have on road infrastructure and have the relation vary between 0 and 2,85. The sensitivity graph is highly similar to the graph of the effect of road infrastructure on economic growth as shown in figure 6.5. It is undefined which type of road is built by an increased economic growth and since the government in Namibia builds both gravel and bitumen roads, both are increased with 1,425 for each % increase in GDP.

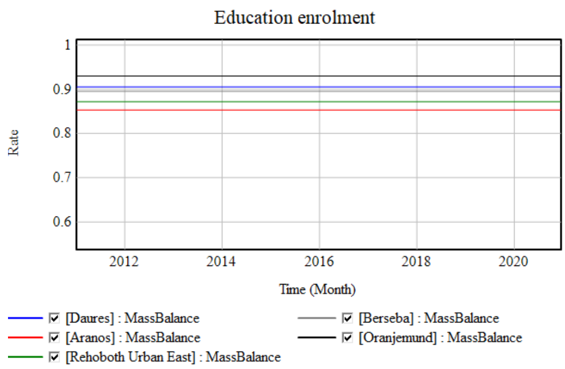
6.5. Verification

Verification of a system dynamics model structure means comparing the model structure directly with the structure of the real system that the model represents (Forrester & Senge, 1980). This requires an assessment of the correct implementation of the conceptual model (Robinson, 1997). A mass balance test on the entire model is conducted as a verification.

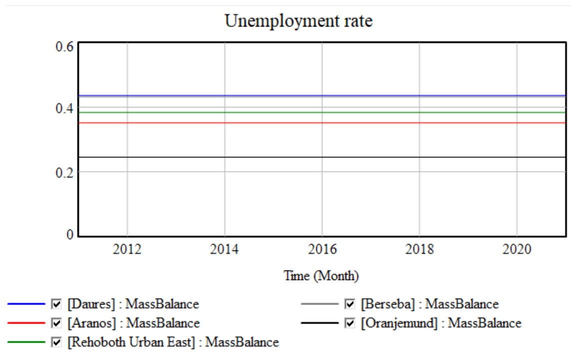
The mass balance test for the entire basic model is executed by setting road construction and upgrading to zero, so there are no changes in the road infrastructure. This means that the total model output should be constant, except for the road safety as this incorporates a small growth independent of the road infrastructure. All other factors and the total GDP growth should be constant, which would confirm correct implementation of the model equations. Figure 6.6 shows the result of the mass balance test for health, education, unemployment and GDP growth.



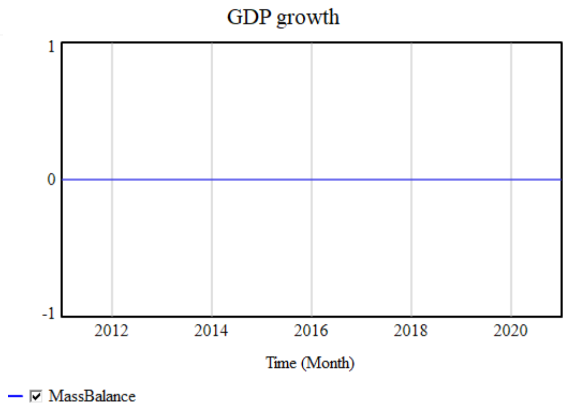
(a) U5MR constituency level



(b) Primary school attendance constituency level



(c) Unemployment



(d) GDP growth

Figure 6.6: Mass balance test for health, education, unemployment and GDP growth

The first three figures are on constituency level and have some random constituencies included to show that they have different initial values but do not change over time.

Adding the uncertainties to the model does not bring any difference, since no roads are constructed or upgraded. Therefore, there is no economic growth due to road infrastructure improvement and no road infrastructure construction or upgrade to the economic growth. All graphs look the exact same as shown in figure 6.6.

6.6. Conclusion | System Dynamics model

RQ6: "What model is developed to investigate the effects between road infrastructure, economic growth, road safety, emissions, education, health, employment and tourism in Namibia in future scenarios?"

To test the effects of improved road infrastructure in future scenarios, a System Dynamics (SD) model is built. An important aspect of SD is the feedback structures, which are represented by feedback loops consisting of causal links from one variable connecting back to that same variable, after connecting to other variables (Sterman, 2000). Feedback loops often play a big role in the overall behaviour of the model which makes it important to identify them. The feedback loop in the framework of this study (figure 1) is represented by the bidirectional relation between road infrastructure and economic growth. The dashed line in the framework indicates the uncertainty of the relationship. Figure 6.2 shows the causal loop diagram of this study, with the uncertain relations indicated by dashed lines. A common way of dealing with uncertainties in SD is to explore the uncertainties, attempt to reduce the uncertainties as much as possible and to accept the irreducible uncertainties (Pruyt, 2013). Two models are developed; one without uncertainties and one with uncertainties. Both models include the following model components: road infrastructure, economic growth, education, health, employment, tourism, road safety and emissions. These variables are connected as shown in figure 6.2. The extended model includes the uncertain relations indicated as dashed lines between road infrastructure and economic growth by using sensitivity analysis varying the magnitude of the relationship between 0 and the maximum value. The multi-scale aspect can mostly be found in the vertical integration. Values are taken from constituency level to country level (education, health, employment) and from region level to country level (tourism and road safety) to get the economic growth for the whole country. Furthermore, values are taken from region level to constituency level for the road quality. The ratios of road material is known per region and this ratio is taken down to constituencies as well. The models are verified with the mass balance test, which tests if the model output remains zero if road construction and upgrading is set to zero.

7

Model Application

This chapter aims to answer the seventh research question: "What are possible future scenarios for Namibia that include road infrastructure improvement and how do they affect education, health, employment, tourism, emissions, road safety and economic growth?". The question is answered with the help of the conceptualised model as explained in chapter 6. Scenarios are developed to obtain insights and answer this research question. To test the different scenarios for their performance, key performance indicators (KPIs) are established. The first section determines these KPIs, where the sections after identify different scenarios and test them on the determined KPIs.

7.1. Key Performance Indicators

This section aims to identify KPIs for which the scenarios have to be tested. The factors that are used in the SD model, hence the ones of which a correlation with road density was found, proved to be influenced by a bigger and/or better road network by both the data as by literature. Therefore education, health, employment and tourism are used as KPIs. Furthermore, as can be seen in figure 2.1, road infrastructure also influences road safety and emissions. Chapter 3 acknowledged that both these variables are of great importance in Namibia, which indicates that they should both be used as KPIs for the assessment of different scenarios. Table 7.1 below shows all KPIs with their used units and the scale the KPIs are measured on.

Table 7.1: KPIs with their units and level/scale

KPI	**Unit**	**Level/scale**
Education	% never attended school	Constituency
Child mortality	U5MR [deaths per 1000 live births]	Constituency
Unemployment	Unemployment rate	Constituency
Tourism	# of tourists	Region/country
Road safety	Injuries	Constituency
Emissions	Tonnage CO_2	Country
Economic growth	GDP	Country

7.2. Scenarios

As came forward in the data analysis, road density and quality are not the biggest predictors of most factors. They are - maybe indirect - small influencing variables but should not be used as a main tool to increase for instance education enrolment. However, insights in the effects of road infrastructure improvements included in plans that are already made can be very useful. The subsections below identify two possible, realistic future scenarios for Namibia's road infrastructure. Ogilvy & Schwartz (2004) define scenarios as the "narratives of alternative environments in which today's decisions may be played out." Scenarios are not predictions, nor strategies, but hypotheses of different futures specifically designed to show both opportunities and risks involved. The aim of a scenario is usually to clarify present action in light of possible and desirable futures (Durance & Godet, 2010).

The purpose of the scenarios in this study is informing policy makers of effects of probable choices in terms of road infrastructure investment in certain areas. It should be noted that road density on itself is a difficult way of expressing road network and it has to be used properly. For instance, road density increases more with the same road length if the surface of one constituency is smaller than another. Besides, costs of investing in road infrastructure are not taken into account in the model itself, but the scenarios as explained below are meant to give a realistic overview and therefore have costs included in the development of the scenario. As mentioned in the conceptualisation of the model, the model generates the changes in all factors solely due to road infrastructure. Changes due to for instance policies or improvements in health or education are not taken into account and the changes due to the improved road network would add up to that growth.

7.2.1. Scenario 1 | Logistics Hub 2022

As discussed in chapter 3.3, Namibia is planning on becoming the logistics hub of Southern Africa by 2022. A part of realising this plan is upgrading existing the transport network. The corridors of importance - connecting the Port of Walvis Bay to neighbouring (land-locked) countries - are Trans-Kalahari corridor, Trans-Cunene corridor, Trans-Caprivi corridor and Trans-Oranje corridor. These corridors are already in place, so the realisation does not take much constructing new roads. Activities mostly include maintaining and upgrading existing roads. Figure 7.1 shows an overview of these corridors. Most of these roads are paved already

Figure 7.1: Road corridors as part of the logistics hub ambitions

but need maintenance or upgrading, mostly to dual carriage (hence two lanes per direction). This increases capacity and enhances road safety. Even though these roads exist already, it can still contribute to the road network of a constituency. For starters, road safety will be better so there will be less accidents. Besides, accessibility of services and people will increase through the improved road infrastructure. The corridors can be broken down into smaller road components, belonging to a constituency. Table 7.2 shows the road lengths of each corridors over different constituencies.

Obviously, there is overlap in some of the corridors; mostly in the surroundings of Walvis Bay. As mentioned before, these road lengths are not directly *extra* roads, but do increase capacity and safety. To implement this in the model, 25% of each road length is inserted as new construction bitumen roads. To account for increased road safety on the roads of these corridors, the road safety value is put to 0,8 in all constituencies these roads cross.

Table 7.2: Road lengths of corridors in constituencies

Trans-Cunene		Trans-Caprivi		Trans-Kalahari		Trans-Oranje	
Constituency	*Km*	*Constituency*	*Km*	*Constituency*	*Km*	*Constituency*	*Km*
Arandis	60	Arandis	60	Arandis	60	Windhoek Rural	74
Karibib	128	Karibib	128	Karibib	150	Rehoboth West	33
Omaruru	87	Omaruru	87	Okahandja	62	Rehoboth Rural	95
Otjiwarango	145	Otjiwarango	145	Omatako	35	Marienthal Urban	63,5
Otavi	105	Otavi	135	Windhoek Rural	145	Marienthal Rural	63,5
Guinas	104	Grootfontein	153	Okorukambe	101	Gibeon	45
Tsumeb	16	Musese	42	Kalahari	111	Berseba	206
Omuthiyagwipundi	101	Ncamagoro	50			Keetmanshoop Rural	80
Onyaanya	25	Ncuncuni	40			Keetmanshoop Urban	11
Onayena	5	Rundu Rural	24			!Nami=Nus	163
Oniipa	16	Mashare	45				
Ondangwa Rural	10	Ndiyona	33				
Okaku	19	Ndona Linena	33				
Okatyali	15	Mukwe	167				
Oshikango	4	Kongola	92				
Engela	4	Linyandi	55				
Ohangwena	12	Sibinda	45				
		Katima Muliro Rural	14				

Input Table 7.3 shows the input of the model for scenario 1. The amount of kilometres is a 25% of the road lengths per constituency as identified in table 7.2. It only consists of bitumen roads. The constituencies that are not mentioned in the table, do not increase in road length.

Table 7.3: Input roads SD model scenario 1

Constituency	Km	Constituency	Km	Constituency	Km
Arandis	15	Ndiyona	8,25	Omuthiyagwipundi	25,25
Karibib	37,5	Ndonga Linena	8,25	Onayena	1,25
Omaruru	21,75	Rundu Rural	6	Oniipa	4
Swakopmund	2,75	Musese	10,5	Onyaanya	6,25
Walvisbay Urban	8,25	Ncamagoro	12,5	Tsumeb	4
Gibeon	11,25	Ncuncuni	10	Grootfontein	38,25
Mariental Rural	15,875	Windhoek Rural	3,5	Okahandja	15,5
Mariental Urban	15,875	Engela	1	Omatako	8,75
Rehoboth Rural	23,75	Ohangwena M	3	Otavi	25
Rehoboth Urban West	8,25	Oshikango	1	Otjiwarongo	36,25
!Nami=Nus	40,75	Kalahari	27,75	Katima Muliro Rural	3,5
Berseba	51,5	Okorukambe	25,25	Kongola	23
Keetmanshoop Rural	20	Okaku	4,75	Linyanti	13,75
Keetmanshoop Urban	2,75	Okatyali	3,75	Sibinda	11,25
Mashare	11,25	Ondangwa Urban	2,5		
Mukwe	41,75	Guinas	26		

7.2.2. Scenario 2 | Tourism enhancing

Tourism is a major contribution to the GDP in Namibia and the government is attempting to keep increasing the number of tourists. The most mentioned improvement in a survey for tourists in Namibia is the infrastructure. This implies that a better road network would attract (more) tourists. This is supported by findings from the literature study in chapter 2.3.4, which show that efficient, reliable and safe travelling is highly valued and that there is a positive effect of road infrastructure on tourist numbers. Chapter 3.2.2 indicated that the number of tourists in Namibia is attraction dependent and is therefore not constituency based. However, it is very likely that the government wants to attract more tourists by investing in roads connecting the major attractions. Most tourists drive similar rounds through the country so the connecting roads would be of high value. The bigger cities are mostly visited by tourists. However, this is probably how people arrive in the country (Windhoek, Walvis Bay and Oshakati) and most roads in these areas are good. For this scenario it is chosen to focus on the more off the grid natural attractions and game parks, because people might not visit Namibia for these purposes now since a 4x4 car is needed for most roads to these sights and it might not feel safe for tourists. Table 6.1 shows the attractions and for this scenario Etosha, Sossusvlei, Fish River Canyon and Damaraland are investigated. Figure 7.2 shows the full circle between these places. Assuming that tourists drive to each of these attractions in the order of the circle, so for instance from Damaraland either to Etosha or to Sossusvlei, there are four roads that can be investigated for their quality (i.e. road type). If the roads have poor quality (earth or gravel roads), these can be upgraded and the effect of this is tested. Table 7.4 shows the type of roads between the four attractions.

Figure 7.2: Route between major touristic attractions Namibia

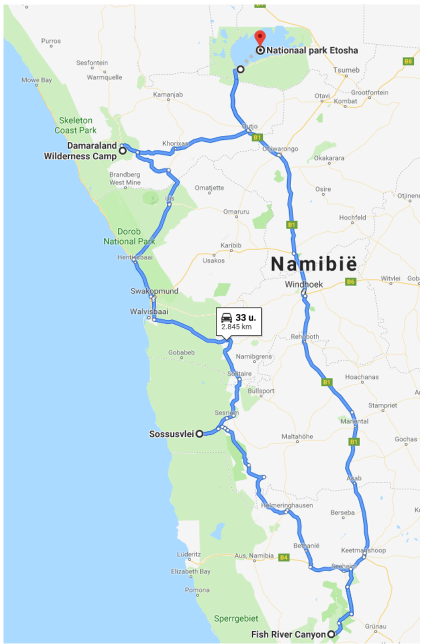


Table 7.4: Four routes and their road type

Route	Km	Road type	Constituencies
Etosha - Damara	343	Major part bitumen (227 km), rest is gravel (116 km)	- Khorixas (116 km)
Damara - Sossusvlei	783	All gravel, except for the entrance of Sossusvlei national park	- Khorixas (143 km) - Daures (125 km) - Arandis (98 km) - Walvis Bay Rural (190 km) - Windhoek Rural (90 km) - Daweb (130 km)
Sossusvlei - Fish River Canyon	602	All gravel, except for a piece of road on the B4 in the south	- Daweb (195 km) - Berseba (202 km) - Keetmanshoop R. (117 km) - Karasburg West (45 km)
Fish River Canyon - Etosha	1089	All bitumen	-

Some of the roads have different types of material along the route. The most right column only shows the gravel roads, so bitumen roads are not taken into account. All gravel roads are updated to bitumen roads, which is inserted in the model. The overlapping pieces of road (mostly entrances to parks) are excluded from the road lengths. The upgrading from gravel to bitumen gives a higher road safety so this variable is set to 0,8 for the constituencies that have (some of their) roads upgraded.

Input Table 7.5 shows the first part of the input of the SD model in scenario 2. All gravel roads between the five major tourism attractions are updated to bitumen.

Table 7.5: Input scenario 2

Constituency	Upgrade gravel to bitumen	New gravel roads	Constituency	Upgrade gravel to bitumen	New gravel roads
Arandis	98	9,8	Karasburg West	45	4,5
Daures	125	12,5	Keetmanshoop Rural	117	11,7
Daweb	90	9	Khorixas	90	9
Berseba	202	20,2			

Secondly, the government can utilise the tourism roads between the four major nature attractions more. Smaller nature attractions and cultural attractions close to the roads between the major attraction could be made more accessible for the tourists that are already there. Therefore, a 10% increase in smaller gravel roads is inserted in the model in all nine constituencies in which the road upgrades are done. This is indicated in the third and sixth column of table 7.5.

7.3. Basic model - results

This section shows and discusses the results of both scenarios ran with the basic model, without uncertainty. The CLD is shown in figure 7.3.

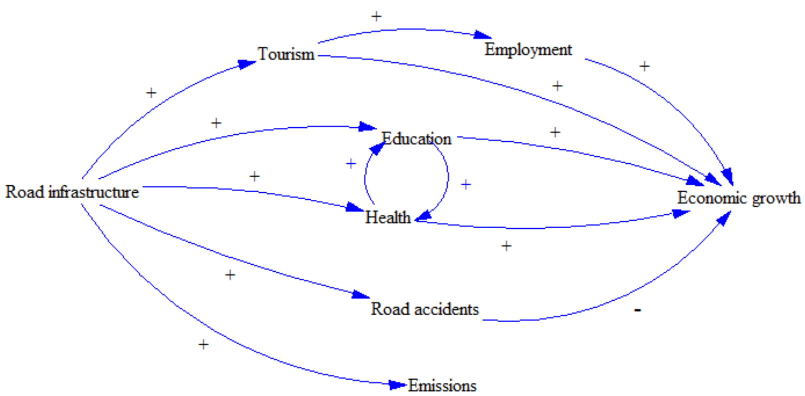


Figure 7.3: Causal Loop Diagram basic model

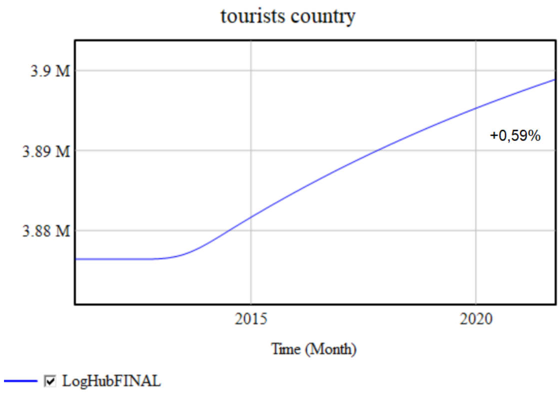
7.3.1. Scenario 1 | Results

Table 7.6 below shows the changes from 2011 to 2022 of the factors health, employment and the number of injuries due to road crashes for a selection of constituencies. The education remained the same for all constituencies between 2011 and 2022, which is why it is not shown in the table. The constituencies as shown are the constituencies crossed by (one of the) corridors with a road density lower than 0,1. Okatyali is excluded since it was concluded in chapter 5 that this value is not right. The unit of each KPI can be found in table 7.1.

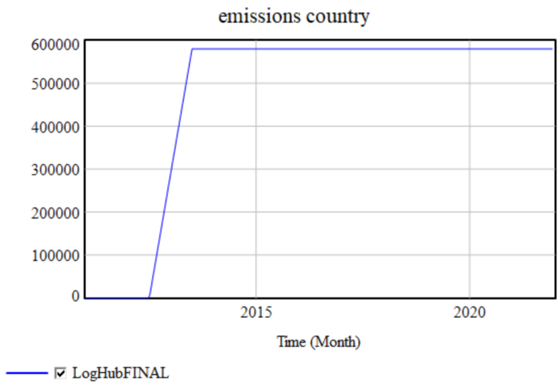
Table 7.6: Output on constituency KPIs - scenario 1

Constituency	Road density		Health		Employment		Injuries	
	2011	*2022*	*2011*	*2022*	*2011*	*2022*	*2011*	*2022*
!Nami=Nus	0,045	0,046 (+2,2%)	39,1	37,1 (-5,1%)	0,28	0,27 (-6,1%)	49	49
Onyaanya	0,051	0,059 (+15,7%)	48,2	31,8 (-34,0%)	0,43	0,41 (-3,5%)	73	75 (+2,7%)
Musese	0,044	0,048 (+9,1%)	187,0	175,8 (-6,0%)	0,49	0,45 (-8,2%)	35	35
Linyanti	0,078	0,085 (+9,0%)	314,7	305,1 (-3,1%)	0,34	0,32 (-7,1%)	26	26
Mariental Urban	0,097	0,1 (+3,1%)	61,3	58,3 (-4,9%)	0,37	0,34 (-8,1%)	53	55 (+3,8%)
Sibinda	0,099	0,106 (+7,1%)	102,6	95,6 (-6,9%)	0,43	0,40 (-6,5%)	39	39

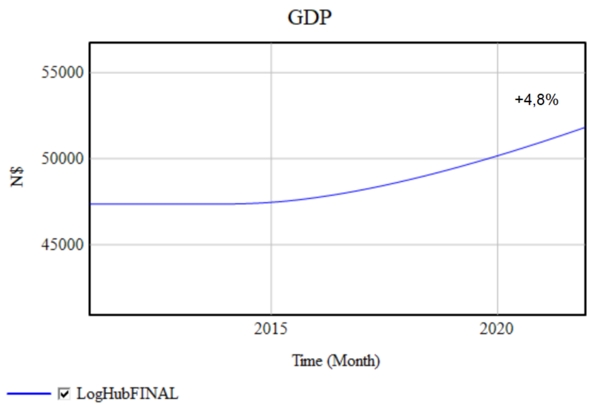
Behind the 2022 score the difference between 2011 and 2011 is indicated, if there is a difference. There is quite a big variety in the differences, especially for health. The minus signs indicate that the U5MR and unemployment rate decrease, which is positive. One can see that the education level remains the same for each constituency. This can be explained by the fact that it is only dependent on road density, which does not increase much. The absolute increase in road length is not that large, but the ratio of road type changes towards a higher quality. This impacts health and employment, where one can see bigger changes from 2011 to 2022. Due to the upgrade of the roads, the road safety increased. Some of the constituencies still have an increasing number of crashes and some remained the same as of 2011. The remaining KPIs that are not on constituency level are tourism, emissions and economic growth. The increase in these factors can be seen in figure 7.4.



(a) Tourists increase



(b) Emissions increase



(c) Economic growth

Figure 7.4: Increase of tourists, emissions and GDP in scenario 1

All three factors increase between 2011 and 2022; the number of tourists increases from 387.641 in 2011 to 389.932 in 2022 (+0,59%), similar to the GDP from N$ 47.358 in 2011 and N$ 51.880 in 2022 (+9,5%). The tonnage CO_2 emissions reaches 290.207 in 2022, by adding the bitumen roads. This is a direct result of the construction of these roads. Hence, it can be concluded that the scenario of becoming the logistics hub of Southern Africa by 2022 will result in an increase of health (lower U5MR), a small decrease in the unemployment rate and an equal or slightly increasing number of injuries. The number of road crashes increases every year and it staying equal means that increasing road safety a bit by upgrading roads to bitumen and dual carriage roads stagnates the yearly increase. If the government would deploy other measures - additionally to the quality improvement - such as more speed - and alcohol controls and awareness campaigns, the number of crashes would decrease more. This scenario is promising in terms of economic growth in general (NPC & JICA, 2015) and the effects due to the improved road network as displayed in figure 7.4c would be additional to that.

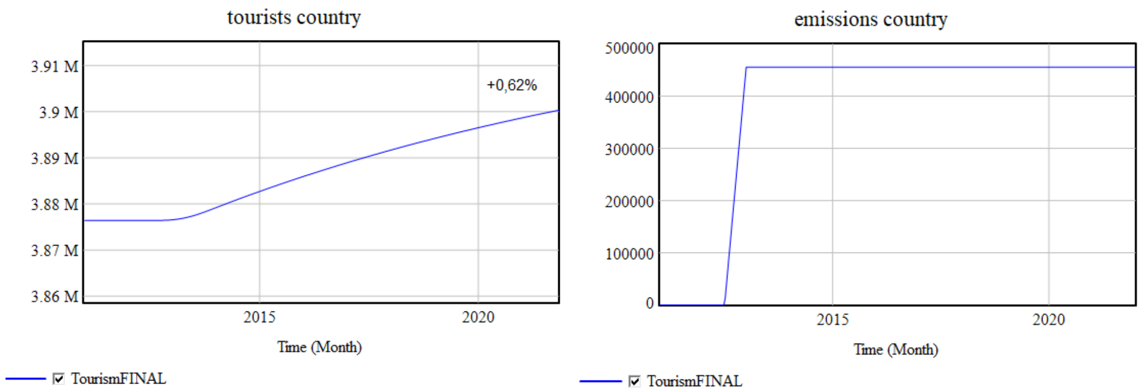
7.3.2. Scenario 2 | Results

Table 7.7 below shows the changes from 2011 to 2022 of the factors health, employment and the number of injuries due to road crashes for a selection of constituencies. The education remained the same for all constituencies between 2011 and 2022, which is why it is not shown in the table. The constituencies as shown are the constituencies crossed by (one of the) corridors with a road density lower than 0,1. Okatyali is excluded since it was concluded in chapter 5 that this value is not right.

Table 7.7: Output on constituency KPIs - scenario 2

Constituency	Road density		Child mortality		Unemployment		Injuries	
	2011	*2022*	*2011*	*2022*	*2011*	*2022*	*2011*	*2022*
Arandis	0,132	0,132	45,1	42,1 (-6,6%)	0,28	0,25 (-10,7%)	35	36 (+2,9%)
Daures	0,173	0,174 (+0,58%)	74,5	72,3 (-3,0%)	0,44	0,41 (-6,8%)	40	40
Walvis Bay Rural	0,111	0,112 (+0,90%)	43,3	38,5 (-11,1%)	0,32	0,29 (-9,4%)	94	101 (+7,4%)
Daweb	0,110	0,110	200,0	196,1 (-2,0%)	0,31	0,25 (19,4%)	20	20
Berseba	0,134	0,134	94,5	91,9 (-2,75%)	0,43	0,41 (-4,8%)	37	37
Karasburg West	0,117	0,117	28,8	27,2 (-5,7%)	0,29	0,26 (-10,3%)	25	26 (+4,1%)
Keetmanshoop Rural	0,109	0,109	113,6	112,1 (-1,3%)	0,35	0,28 (-20,0%)	25	25
Windhoek Rural	0,307	0,307	66,9	66,5 (-0,6%)	0,23	0,23 (-1,5%)	67	70 (+4,5%)
Khorixas	0,145	0,145	177,4	173,6 (-2,1%)	0,47	0,44 (-6,4%)	44	45 (+2,3%)

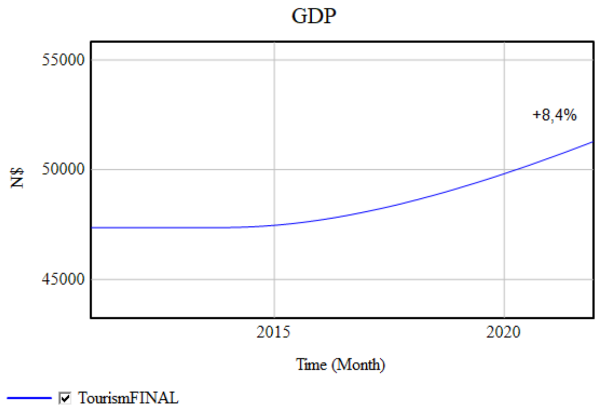
All nine constituencies in which roads between the touristic attractions pass are shown. The unit of each KPI can be found in table 7.1. No new roads were constructed so the road density remains the same for all constituencies. If there is a difference between the values for 2011 and 2022, this is indicated in % behind the 2022 value. Both health and employment show quite large improvements for some constituencies. This indicates that in terms of those two factors, the upgrading of roads to enhance tourism would be very beneficial. The number of injuries remains the same for some constituencies and increases in other cases.



(a) Tourists increase

(b) Emissions increase

More road safety measures could be taken to decrease the number of injuries. The remaining KPIs are tourists, emissions and economic growth. The performance over time of each of these KPIs can be seen in figure 7.5. All three factors increase between 2011 and 2022; the number of tourists rises from 387.641 in 2011 to 390.062 (+0,62%). This growth is twice as large as the first scenario that is not focused on tourism, which indicates that upgrading roads from gravel to bitumen between the attractions has a positive and desired impact on tourism. The emissions in this scenario are larger then for the road construction of the logistics hub scenario, due to the fact that more kilometres road are constructed. The GDP increases from N$ 47.358 to N$ 51.333 (+8,4%), which is a larger increase in GDP than in scenario 1. However, the number of tourists has a direct impact on GDP growth and when this increases, the GDP increases as well. Still, the GDP is also driven by the increase in health and employment, so it can be concluded that this scenario would be beneficial for all factors, except for education (no demonstrable change) and emissions, but there will always be emissions when upgrading or constructing roads.



(c) Economic growth

Figure 7.5: Increase of tourists, emissions and GDP in scenario 2

7.4. Extended model with uncertainties - results

This section shows and discusses the results of both scenarios ran with the extended model, with uncertainties. The CLD is shown in figure 7.6. It is important to note that bidirectional causality as can be seen here

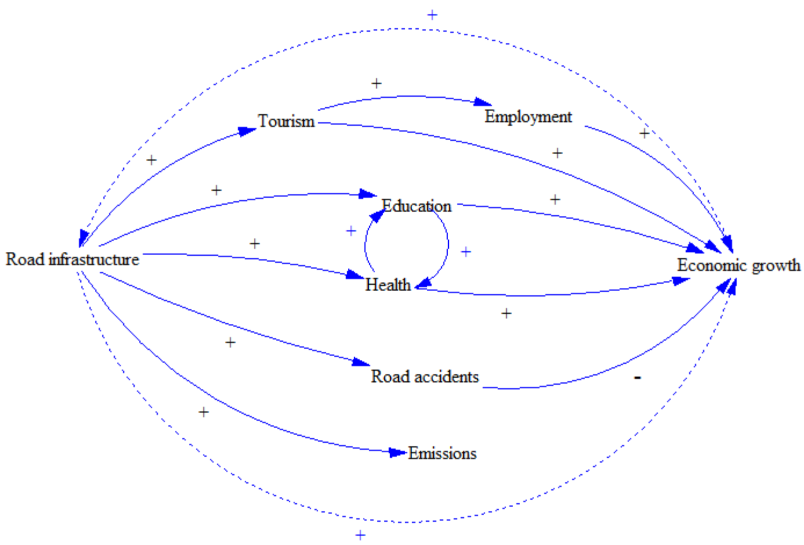
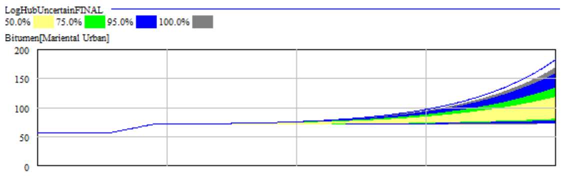


Figure 7.6: Causal Loop Diagram extended model

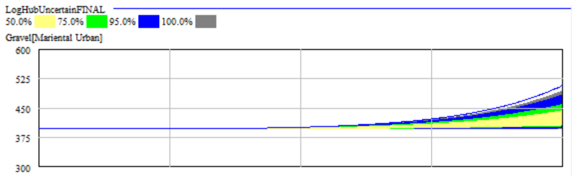
is a complex and non realistic structure. If one variable causes the other variable to rise and if that is also true when the variables are switched, the variables would reinforce each other and the loop would be self-reinforcing. This is not the case in real life, which means that the results of this model with uncertainties does not serve to show the exact effects of changes in the road infrastructure, but to give insight in the possible result of the uncertainties. For this reason, sensitivity graphs are presented in this chapter of the variables on country level.

7.4.1. Scenario 1 | Results

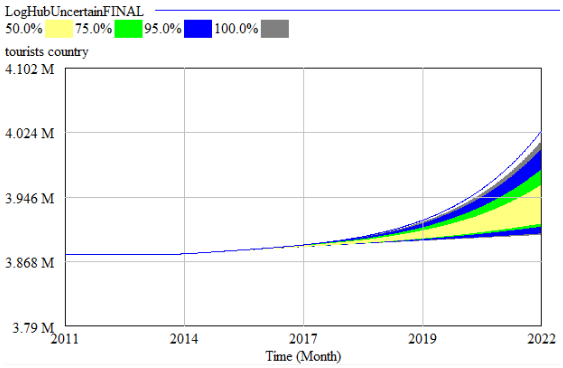
Table 7.7 shows the sensitivity graphs on eight variables in the first scenarios.



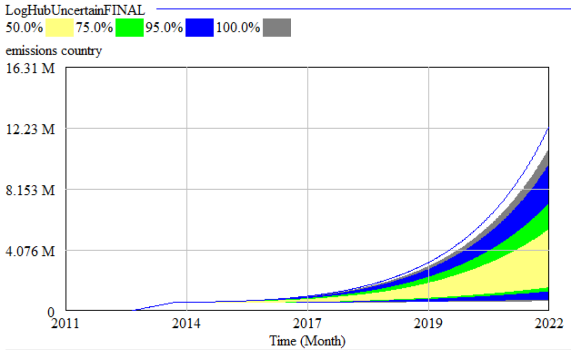
(a) Bitumen roads



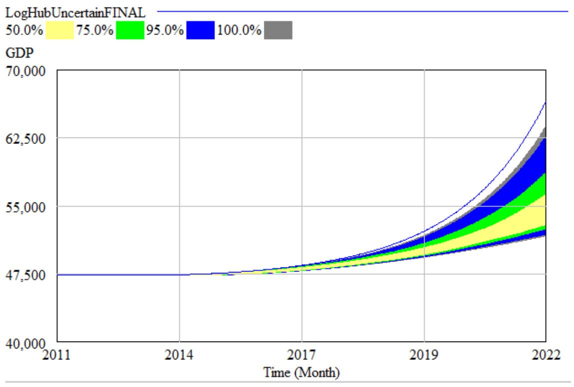
(b) Gravel roads



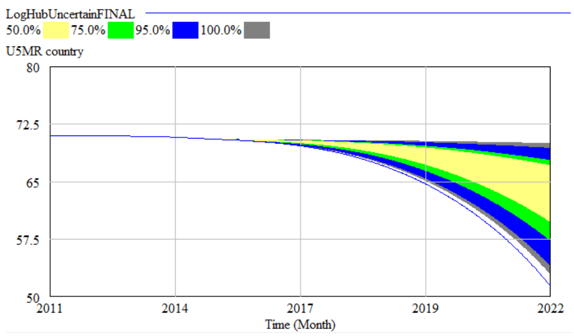
(c) Tourists



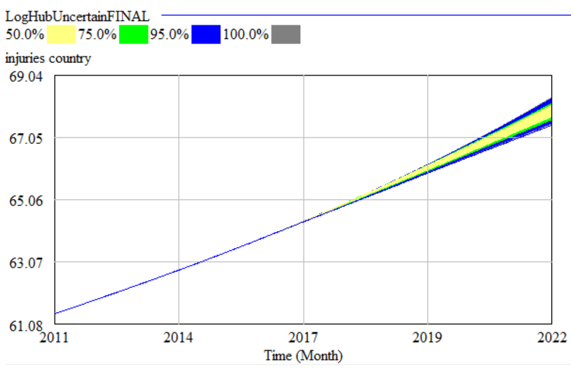
(d) Emissions



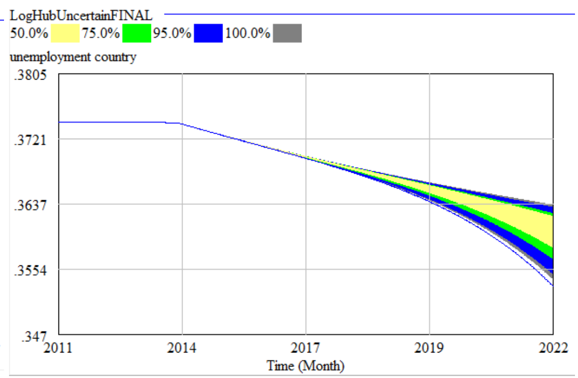
(e) GDP



(f) U5MR



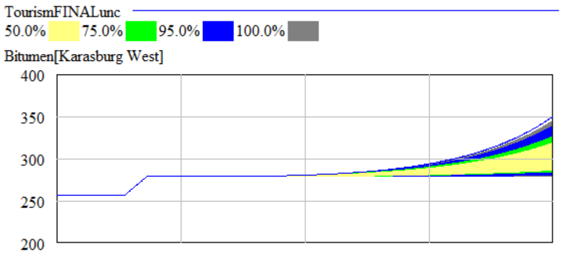
(g) Injuries due to road accidents



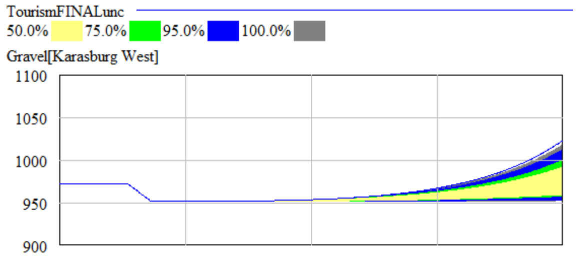
(h) Unemployment

Figure 7.7: Sensitivity graphs scenario 1 of bitumen roads, gravel roads, tourists, emissions, GDP, U5MR, injuries and employment

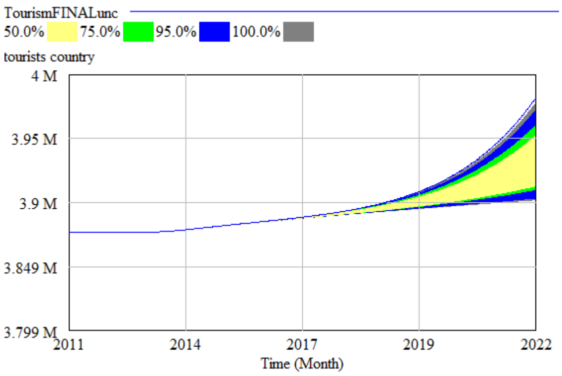
7.4.2. Scenario 2 | Results



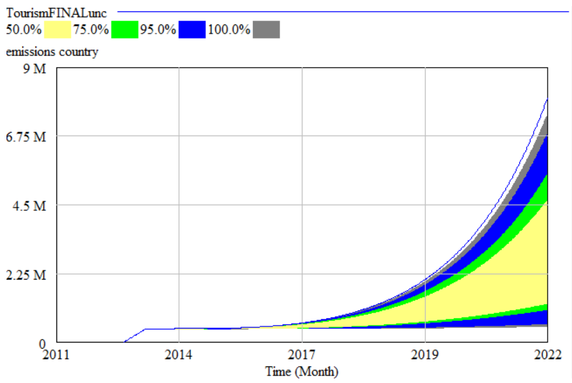
(a) Bitumen roads



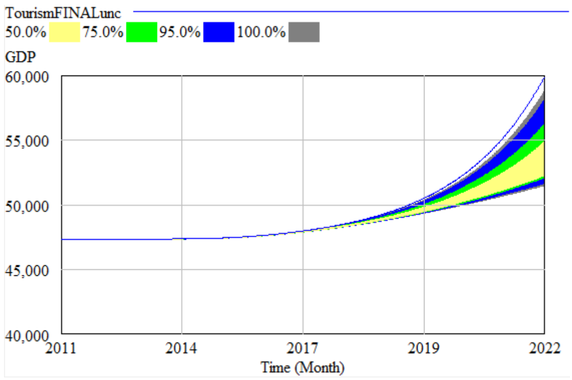
(b) Gravel roads



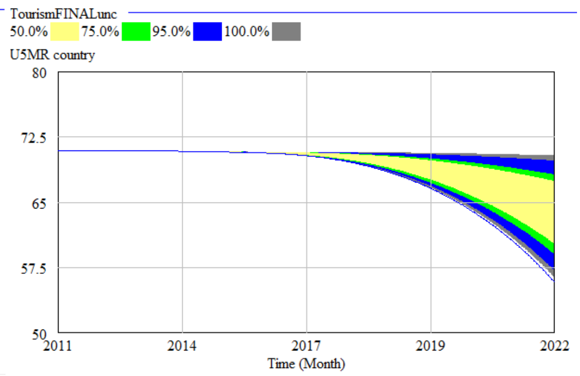
(c) Tourists



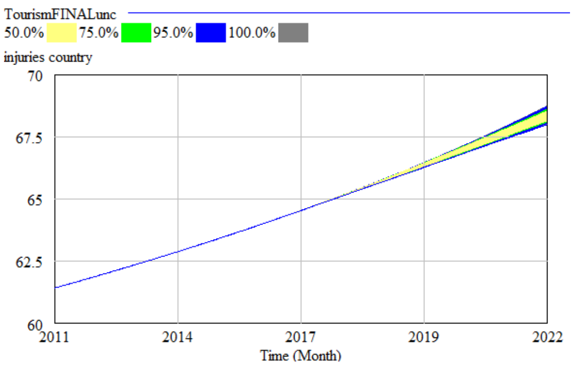
(d) Emissions



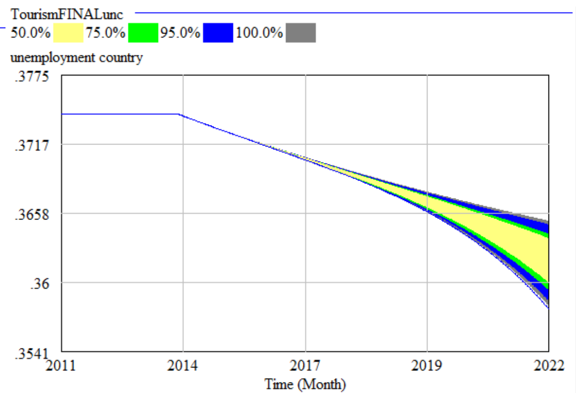
(e) GDP



(f) U5MR



(g) Injuries due to road accidents



(h) Unemployment

Figure 7.8: Sensitivity graphs scenario 2 of bitumen roads, gravel roads, tourists, emissions, GDP, U5MR, injuries and employment

Sensitivity analysis mostly serves as a tool to assess the change of a parameter's behaviour when adding uncertainty to the model. For all parameters shown in the figures of both scenarios above, the magnitude of the variables labelled as uncertainty (the effect of road infrastructure on economic growth and reversed) determines the extent of the growth. The structural behaviour does not change, but one can see that the parameters are quite sensitive to the addition of these uncertain relations. This makes sense, since the feedback loop is self-reinforcing; if for instance new roads are constructed, the economic growth will evidently increase, which increases building road infrastructure again. This self-reinforcing of road infrastructure and economic growth is not something that actually happens in the real world, which is why one should keep in mind that the behaviour as comes forward to a model with the positive closed feedback loop (which causes self-reinforcing behaviour) should be interpreted wisely.

7.5. Conclusion | Model application

RQ7: "What are possible future scenarios for Namibia that include road infrastructure improvement and how do they affect education, health, employment, tourism, emissions, road safety and economic growth?"

In this chapter two possible scenarios are identified: Namibia as the logistics hub of Southern Africa by 2022 and tourism enhancing. The first one includes the upgrading of the existing road corridors that connect Walvisbay Port with the hinterland. This has a positive effect on most factors; all constituencies will experience a decrease in U5MR and unemployment rate, tourism and GDP will increase and the number of crashes stagnates. The second scenario is that of enhancing tourism by upgrading the roads between the four major nature attractions. This has a positive effect on the number of tourists (+0,62%) which also positively impacts the GDP. Besides, health and employment improve and road safety increases in some of the constituencies. Road safety could be further improved if extra measures are taken. The upgrading of the roads could include some extra measures such as a separation from the land next to the road, which would be beneficial for the tourism industry as safe infrastructure is of great importance to tourists. As for comparing the scenarios; both scenarios are realistic scenarios. The second one is more focused on using roads as a mean for increasing tourism. Therefore, this scenario attracts more tourists. Other than that, both scenarios improve health and employment. Both scenarios would be beneficial for the social factors and besides, the scenarios could also be combined and be executed at the same time. This would increase the magnitude of the effect of most factors.

Including the uncertainties mostly by sensitivity analysis mostly serves as a tool to assess the change of a parameter's behaviour when adding uncertainty to the model. For all parameters shown in the figures above, the magnitude of the variables labelled as uncertainty (the effect of road infrastructure on economic growth and reversed) determines the extent of the growth. The structural behaviour does not change, but one can see that the parameters are quite sensitive to the addition of these uncertain relations. This makes sense, since the feedback loop is self-reinforcing; if for instance new roads are constructed, the economic growth will evidently increase, which increases building road infrastructure again.

8 Conclusion

The objective of this final chapter is to conclude and discuss the research. The two main objectives - developing a method to investigate the effects of an improved road network on societal factors and secondly applying this on the country Namibia are achieved by answering the seven research questions. First, section 8.1 discusses the answers to all these questions and provides an overview of the gained insights. Secondly, section 8.2 shows some extra insights for the country Namibia. The third section 8.3 extensively discusses this research by reflecting on the results and the methods used to conduct the research. Hereafter, the limitations of the research are given. The chapter concludes with recommendations for further research in section 8.4.

8.1. Research Conclusions

In this study, a system dynamics model is developed which can be used to assess the effects of improvements in road infrastructure on the factors economic growth, road safety, emissions, education, health, employment and tourism. Furthermore, the relations between road infrastructure and the same factors are quantified for Namibia based on literature study and data-analysis. Lastly, two possible future scenarios for Namibia concerning road infrastructure are identified and used as input for the SD model, which showed the usefulness of the SD model and led to insights for the case of Namibia. These insights are discussed below. The remainder of this section includes the answers to all seven research questions, a follow-up on the two objectives and the insights gained with this research on the effects of improved road infrastructure in Namibia.

8.1.1. Answering the research questions

This section answers all research questions as discussed throughout this study. These questions are posed in section 1.1 and are answered one by one below.

RQ1: What are the relations between road infrastructure, economic growth, road safety, accessibility and emissions in developing countries based on literature?

Figure 8.1 summarises all relations as found in literature. There is a bidirectional relation between road infrastructure and economic growth. As for the relation from economic growth to road infrastructure, there is not a direct guarantee of having higher GDP automatically resulting in more road infrastructure. However, having a higher GDP does mean that there is more room for expenditure for road infrastructure, and a growing economy is also likely to contribute to the increase of both freight and passengers increases. Secondly, road infrastructure positively influences general accessibility. Underlying this relation are factors health, education, employment and tourism which are all positively influenced by an improved road network. The four factors have reciprocal relations as well and each of the factors has a positive effect on economic growth when improved. The relation between road infrastructure and road safety is not uniformly defined, since the quality of the road is of great importance. The type of road (for instance gravel or bitumen) correlates with the road safety on that road. However, road safety is a major issue in most developing countries and the number of crashes is increasing and is predicted to keep increasing. Road traffic injuries cost governments between 1% and 3% of their gross national product on yearly basis. Lastly, building, maintaining and upgrading road infrastructure causes a lot of emissions by the materials used for it, the construction itself, the maintenance and the extra vehicle movements as a result of roads. The largest amount of emissions is caused by the materials.

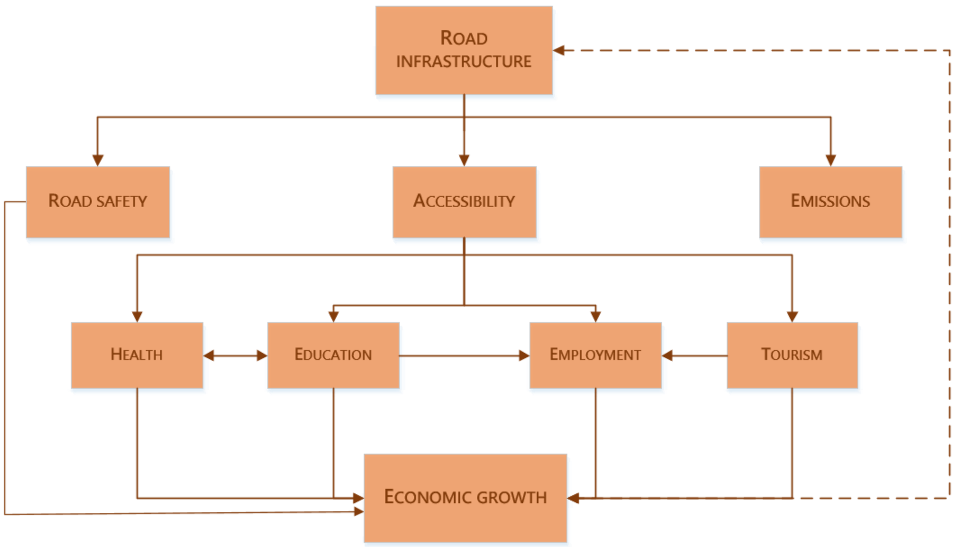


Figure 8.1: Theoretical framework based on literature study

RQ2: What is the socio-demographic status of Namibia and how does the current accessibility affect this?
To answer this question, three main pillars of socio-demographic status are used: population, economy and infrastructure. As for the **population**, there were 2.113.077 people living in Namibia in 2011 and predictions are that it will grow up to a size of 2.960.000 in 2030. Inhabitants have a variety of ethnicity and many different languages are spoken. Education rates are relatively high in primary school but start to drop in secondary school. It is acknowledged in the NDP that there is a lack of access to quality education and training opportunities. A better accessibility to facilities offering these opportunities through an improved road network, could reduce the lack of access. Health care has improved over the past years, but there is still room for improvement. With regards to accessibility, the government concludes that poor people in rural areas often lack most basic features which makes it difficult to remain in good health. Lastly, there is a high unemployment rate in Namibia, mostly among youth. This rate is higher in rural areas and this might be an indication of a poor accessibility to employment in rural areas. As for the **economy**, the country enjoys an economic growth each year, but the magnitude is highly dependent on droughts. The sectors mostly contributing to economic growth are agriculture, MSME, manufacturing, mining and tourism. As for the **infrastructure**, there is a continuous scarcity of water in Namibia. Demand keeps increasing so this is a major issue for Namibia. The electricity situation is sufficient and quite stable in urban areas, but lacking in rural areas. The same goes for ICT services, which the government attempts to improve.

RQ3: What is the current transport infrastructure situation in Namibia?
Namibia's current transport infrastructure is relatively good and extended. The most advanced transport infrastructure is the road infrastructure, whereas rail infrastructure needs improvement and extension to make it a more attractive modality for both passengers and freight. There are attempts to improve the current transportation situation in Namibia in terms of safety, social and economic problems and sustainability. However, no reports on the actual outcomes of these attempts have been published yet and therefore it is hard to gauge if the projects improved the addressed issues. Besides, given past developments and future ambitions such as becoming the logistics hub of Southern Africa by 2022, the reality is that the road sector will keep on investing in roads in the near future.

RQ4: What is the relationship between road infrastructure, education, health, tourism and employment in Namibia?
The relations are tested by conducting (multiple) regression analysis where possible. If data allowed it, variables identified in the frameworks as discussed in sections 2.3.1, 2.3.2 and 2.3.3 were used to explain the factors more than solely using the road density. All three factors of which there is data on constituency level show a significant linear relation with road density, hence it can be concluded that road density positively affects education, health and employment. As for tourism, there is no data available on constituency level

but by looking at number of tourists and how they are divided over the country, it gets clear that this number is highly dependent on the attraction in the area. This generates information on the number of tourists in each region. Based on literature and research by the Namibian government about opinions of tourists with regards to improvements, it is likely that an improved road network enhances tourism.

RQ5: What are possible underlying explanations for constituencies with similar road densities and discrepant performances on the factors?
There is not one major reason for discrepancy in performance for similar road densities, although probably the main reason for a lot of constituencies having a low road density is the large uninhabited areas in the constituency. Another reason is that some of the (mostly northern) constituencies do not have many roads themselves but are close to other big towns so they still have quite good access to facilities. A third reason can be the shapefile containing mistakes. All in all, there is no easy way of accounting for discrepancy in performance of constituencies with similar road densities. These different explanations indicate that road density is not a comprehensive and strong indicator of road infrastructure. Unless used tactfully and logical, road density is not a meaningful way of measuring or assessing road network. An increase in road density could - in theory - imply constructing new roads anywhere within a constituency and performance on factors would go up (according to the data analysis). Therefore, one should bear in mind that, when using road density as a metric, attention has to be paid on where to construct roads and how much. Hence, if road density is used as a metric to assess road infrastructure, it should be used carefully and well-thought-out. To do so, future scenarios are identified in the next section that take this into account.

RQ6: What model is developed to investigate the effects between road infrastructure, economic growth, road safety, emissions, education, health, employment and tourism in Namibia in future scenarios?
To test the effects of improved road infrastructure in future scenarios, a System Dynamics (SD) model is built. An important aspect of SD is the feedback structures, which are represented by feedback loops consisting of causal links from one variable connecting back to that same variable, after connecting to other variables (Sterman, 2000). Feedback loops often play a big role in the overall behaviour of the model which makes it important to identify them. The feedback loop in the framework of this study (figure 1) is represented by the bidirectional relation between road infrastructure and economic growth. The dashed line in the framework indicates the uncertainty of the relationship. Figure 6.2 shows the causal loop diagram of this study, with the uncertain relations indicated by dashed lines. A common way of dealing with uncertainties in SD is to explore the uncertainties, attempt to reduce the uncertainties as much as possible and to accept the irreducible uncertainties (Pruyt, 2013). Two models are developed; one without uncertainties and one with uncertainties. Both models include the following model components: road infrastructure, economic growth, education, health, employment, tourism, road safety and emissions. These variables are connected as shown in figure 6.2. The extended model includes the uncertain relations indicated as dashed lines between road infrastructure and economic growth by using sensitivity analysis varying the magnitude of the relationship between 0 and the maximum value. The multi-scale aspect can mostly be found in the vertical integration. Values are taken from constituency level to country level (education, health, employment) and from region level to country level (tourism and road safety) to get the economic growth for the whole country. Furthermore, values are taken from region level to constituency level for the road quality. The ratios of road material is known per region and this ratio is taken down to constituencies as well. The models are verified with the mass balance test, which tests if the model output remains zero if road construction and upgrading is set to zero.

RQ7: What are possible future scenarios for Namibia that include road improvement and how do they affect education, health, employment, tourism, emissions, road safety and economic growth?
Two possible scenarios are identified: Namibia as the logistics hub of Southern Africa by 2022 and tourism enhancing. The first one includes the upgrading of the existing road corridors that connect Walvisbay Port with the hinterland. This has a positive effect on most factors; all constituencies will experience a decrease in U5MR and unemployment rate, tourism and GDP will increase and the number of crashes stagnates. The second scenario is that of enhancing tourism by upgrading the roads between the four major nature attractions. This has a positive effect on the number of tourists (+0,62%) which also positively impacts the GDP. Besides, health and employment improve and road safety increases in some of the constituencies. Road safety could be further improved if extra measures are taken. The upgrading of the roads could include some extra measures such as a separation from the land next to the road, which would be beneficial for the tourism industry

as safe infrastructure is of great importance to tourists.

Including the uncertainties mostly by sensitivity analysis mostly serves as a tool to assess the change of a parameter's behaviour when adding uncertainty to the model. For all parameters shown in the figures above, the magnitude of the variables labelled as uncertainty (the effect of road infrastructure on economic growth and reversed) determines the extent of the growth. The structural behaviour does not change, but one can see that the parameters are quite sensitive to the addition of these uncertain relations. This makes sense, since the feedback loop is self-reinforcing; if for instance new roads are constructed, the economic growth will evidently increase, which increases building road infrastructure again.

RQ8: How does this research apply to other developing countries?
The first part of this research developed a theoretical framework based on literature on the relations between transport infrastructure and education, health, tourism, employment, transport safety and emissions and economic growth in developing countries. This is a general framework that can be applied to any developing country. The second step is the analysis of the socio-demographic status and the transport infrastructure of the chosen country. Knowing that there often is not much data available in developing country, data analysis can be conducted. The researcher is highly dependent on the availability of the data and the metrics that are used. Humanitarian websites such as HDX and shapefile libraries of for instance all countries in Africa (maplibrary) are very useful. The outcomes confirm or eviscerate the relations as identified in the framework and with a country-specific framework, an SD model can be conceptualised. Empirical studies with similar context can fill the gaps of unknown magnitudes of relations. Different scenarios in terms of transport developments must be identified and inserted in the model. All these steps together form the method for investigating the effects of improved transport infrastructure on education, health, employment, tourism, transport safety and emissions in developing countries.

8.2. Insights case Namibia

Chapter 3 up to 7 are Namibia specific. Apart from the insights that can be derived from the answers to the research questions in the previous section, some extra insights are given in this section.

First of all, a part of the reason that Namibia is used as a case study for this research is the census data availability. The household census data is of good quality and gives a good representation of the country with regards to many different aspects. This data availability makes that a variety of researches from different disciplines can research the country. Hence, having well-structured and complete data is highly valuable and gives Namibia a head start compared to other developing countries. Unfortunately, data on road infrastructure is very limited which made this research difficult. If data would be available, a research like this could be performed more thoroughly and would be more accurate and useful.

This study determined the relations between road infrastructure and education, health and employment on constituency level. Firstly, primary school enrolment is only slightly dependent on the road density and not at all on road quality. This implies that accessibility is not that much of a determining factor for education in Namibia. Health on the contrary - expressed in U5MR - shows to be mostly dependent on the road quality and besides on road density and the access to water. The lack of access to safe water is the number one cause for diarrhoea diseases which count for a significant percentage of deaths of children under five. Hence, this proves that increased safe water access would decrease the U5MR. Interestingly enough, health facilities per surface is not a determining variable for the U5MR. All together, this means that the health of people would benefit from an improved road network, both in terms of road length and better quality. Thirdly, the unemployment rate is determined by road density and quality. There are no other factors found to be available in terms of data that would describe unemployment. The unemployment mostly depends on the quality of roads and not on road density. However, both these variables only have a small impact on the unemployment rate. Still, the unemployment decreases by higher road density and road quality. Concluding, all three factors (education, health and employment) slightly benefit from more roads and health and employment show most improvement by increasing quality of roads.

It cannot be proven that tourism is road- density or quality dependent. Looking at the number of tourists in each region, it appears that tourism is highly attraction based. It was found that most tourists highly value a good infrastructure and it is their number one remark on improvement for tourism in Namibia. Supported by literature and the framework, tourism would be increased by a better road network.

Lastly, this study identified two future scenarios with regards to road infrastructure. Firstly, Namibia is pursuing its ambition of becoming the logistics hub of Southern Africa by 2022. The first scenario attempts to give insights in the effects of the upgrading of roads belonging to the four corridors connecting Walvisbay Port to the hinterland on the concerning constituencies. The outcome is that health, employment and tourism would benefit from the improvements of these roads. Dependent on the effort on increasing road safety, this scenario could also decrease the number of road crashes and therefore injuries and fatalities. Injuries and fatalities are found to have a large impact on the GDP. The second scenario drawn for the Namibia case is that of enhancing tourism. The outcome of this scenario is that tourism would be increasing if the roads between the four major natural attractions are improved in terms of quality. Besides, both health and employment benefit from these upgrades; the U5MR and unemployment rate decrease in all constituencies the roads connecting the four attractions pass.

8.3. Discussion

Having summarised the results in the previous section, a discussion of those results and the methods is presented here. The section starts by looking into the focus of this research on developing countries and the country Namibia in specific. Secondly, the usage of the results of the data analysis are discussed and thirdly the appropriateness of a SD modelling approach for spatial transport dynamics is discussed, including the multi-scale modelling.

8.3.1. Data

As discussed throughout this research, there is a major lack of data. This is not just the case for Namibia, but is most probably worse for most other developing countries. The lack of information resulted in the use of metrics that are not the most practical ones. Optimally, accessibility of an individual or of facilities can be determined, let it be roughly, but in the case of Namibia, it is unknown where exactly individuals live within each constituency. In addition, the fact that some of these constituencies have surfaces up to 40.000 km^2 makes it very difficult to assess accessibility. Therefore, this research used road density as a metric. Unless used tactfully and logically, road density is not a meaningful way of measuring or assessing road network. There are a few things that should be noted when using this metric: (i) an increase in road density could - in theory - imply constructing new roads anywhere within a constituency and performance on factors would go up (according to the data analysis). Therefore, one should bear in mind that, when using road density as a metric, attention has to be paid on where to construct roads and how many. (ii) Namibia is a difficult country to analyse with road density due to its uninhabitable areas and large parts of the country being privately owned. Both these areas are counted as surface in the constituency surfaces, which makes road density extremely low in some constituencies. Road density is the major metric used in this research to assess the road network, but not the only one. Road quality is used in the regression analysis in terms of road type (bitumen, gravel or earth) and in the model. However, there is no data available on constituency level, only in regional level. One of the advantages of the multi-scale modelling as used in this research is that a value of a higher level can be used on the lower levels if no data is available on that level. Therefore, analysis could be done with the road quality, but it is not as specific as for road density, of which each constituency has its own value.

8.3.2. Developing countries

To my opinion, the reason that developing countries are under-investigated lies in the lack of data. This causes some 'vicious circle' of there being so little research available that a researcher would sort of have to start from scratch. This makes that not many people grab the opportunity to perform research on developing countries. The lack of data definitely hinder and slow down research but it might result in more imaginative and improvised solutions than 'usual' research would result in. One should be prepared for having to change course every now and then but if this is managed, it might result in something highly contributing. As for this research, the deviation of the normal way of researching in general and in this case accessibility made it difficult to dive into the real transport side. The result might be a bit divergent from the usual but nonetheless provided some interesting insights. Secondly, this research started from a developing country perspective, but throughout the research I read a book on facts about the world and why it is going better with the world than we think. This book is written by Hans Rosling and reflects on why we - including professors on the relevant topics - systematically underestimate the positive development the world goes through (Rosling et al., 2018). Obviously he does not deny the dreadful matters such as global warming and ongoing poverty and hunger, but he focuses on the improvements that have been made and how we can continue improving. One of his major concerns is the fact that the world is still divided into developing and developed while this is - in his opinion - completely outdated. He suggests a new, more relevant and useful way of dividing the world, namely four income levels. As I started with the thought of researching developing countries, I now think we should focus more on these four income levels and that future research should be from that perspective instead of the outdated developing versus developed world.

8.3.3. Namibia as a case

Namibia is a difficult country to research, due to the reasons why it is difficult to research developing countries in general and because of the low population density, large uninhabitable areas and an existing road network which is good and bad at the same time. To start with the latter, Namibia's road network is said to be the best one in Africa. It is, at times, but some pieces of road are in such poor condition that they are barely passable by car. This makes that it is quite difficult to analyse the road infrastructure country wide and to find out the real quality of the road. Gravel roads can go from potholes every other metre or a perfectly fine road. Furthermore, the low population density reduces the amount of people positively affected by x kilometre new or upgraded road. Namibia is the country with - by far - the highest amount of kilometres road per person in Southern Africa (Savage et al., 2013). This also means that the expenses for road infrastructure are relatively higher for this country. Thirdly, the uninhabitable areas make research on road infrastructure by using road density difficult because large areas are not covered by roads, but the surfaces of these areas do count in the road density value. Therefore, largely uninhabited constituencies might have a low road density but good performance because all people live in one city with proper infrastructure (for instance !Nami=Nus). All this made it a difficult but mostly challenging research.

8.3.4. Results of data analysis

Assuming a linear relation between variables requires a high generalisation. Averages are taken of all constituencies to gain insights in the relation between two variables, which means that - in this research' case - different performances for similar road density smooth to one equal performance. By doing this, all constituencies are affected equally by more or better roads, where one would expect to have a bigger difference for constituencies with a current poor performance. Other shapes than linear relations were tested, but were not found to be significant with the used data. The biggest reason for this is probably the usage of road density as a metric. It became clear that this is not a very strong indicator, mostly due to large uninhabited areas which are counted in the road density metric. Ideally, better data would result in a more suitable and representative indicator of the road infrastructure, for instance the accessibility to different facilities in terms of time or distance. With this, the data analysis would probably be more accurate too and in this case, multiple regression analysis would give representative results. As for the data analysis done in this research, the identified relations do not serve as entirely valid and realistic relations, but they do indicate a relation which complies with literature. Therefore, it was still useful for the SD model, with the note that it should be considered to serve the purpose of facilitating *insights* in the dynamic system of road infrastructure and all factors and not a given and definite relation.

8.3.5. System Dynamics

The use of system dynamics is highly useful for modelling and investigating large dynamic socio-technical systems. However, SD is not very suitable for spatial dynamics; it is not impossible but it is not the most logical and easy method. A more suitable method for this topic study has been developed while writing this research. AnySim is a cloud-based simulation software supporting multi-scale incorporating system dynamics modelling, agent-based modelling (ABM) and discrete-event simulation. By combining different methods (multi-method), this software would be suitable for including transportation networks and the effects on society on a geospatial scale.

Besides, the benefit of feedback loops in system dynamics is not fully employed since there are no reciprocal relations between the factors. Therefore, the behaviour might be quite straightforward. It is very likely that other cases would have more of these relations and therefore more feedback loops in the model. For these cases, system dynamics would be even more beneficial. Furthermore, one of the pitfalls of using system dynamics is the fact that the model is highly based on causal relations, while causality is not always known. It is of great importance to have sufficient support for all causal relations used in the system dynamics model. Since the relations are highly context dependent, it would be better to have case-study specific causality on all variables, but one should bear in mind that this is highly time-consuming.

A third reflection on the use of SD modelling is the usage of the major feedback loop between road infrastructure and economic growth. It is important to note that bidirectional causality as can be seen in this feedback loop is a complex and non realistic structure. If one variable causes the other variable to rise and if that is also true when the variables are switched, the variables would reinforce each other and would be self-reinforcing, which would be a situation that is easy to handle by the policy maker (Chontanawat, 2010; Pradhan & Bagchi, 2013). This self-reinforcing of road infrastructure and economic growth is not something that actually happens in the real world, which is why one should keep in mind that the behaviour as comes forward to a model with the positive closed feedback loop (which causes self-reinforcing behaviour) should be interpreted wisely.

Multi-scale modelling Using the multi-scale modelling approach definitely bears fruit for this type of research and mostly in combination with system dynamics. The combination with system dynamics is of contributing value for both scientific research and societal purposes. Using multi-scale modelling leads to the possibility of decision-making on different levels, for instance education, health and employment wise data is available on constituency level and hence decisions can be made on that level. For tourism it makes sense to make regional and country policy and decisions. This can all be done based on the same model. By using multi-scale modelling in this study, it was possible to include all 121 constituencies while making a relatively simple model.

8.4. Further research

Due to the highly aggregated level of this research, many ideas for further research have evolved. The major and most interesting ones are highlighted below. Four recommendations for further research have come forward. Firstly, as this research proposed a method for developing countries, this method can be applied to many of these countries. Once more countries are researched, the outcomes could be compared or combined as well. For instance, for Namibia it would be interesting to know the effects of road infrastructure on the factors in neighbouring countries South Africa, Botswana, Zambia, Zimbabwe and Angola. The combination should include the logistics hub 2022 ambitions to see what the effects are on the whole region and if it has extra benefits. Secondly, a lot of assumptions are made on different factors and variables due to the scope and time limitation. Each factor and relation between factors and road infrastructure could be investigated more and more extensively. For instance it is not taken into account if there is a difference in quality in health services (hospital, clinic, health service, etc.) or in the capacity of both health care facilities and education facilities. Another example is the fact that there was no data available on locations of jobs and other determining variables for employment.

Thirdly, the research only included correlations now which do not indicate direction. It is well-founded to assume causality based on literature study, but it would be better if causality could be investigated. This could be done by having data from different moments in time. For Namibia, this would be relatively simple since they have census data every 10 years. This implies that solely extra information over time on road infrastructure is needed. Hence, the road length and quality in Namibia should be recorded over time, so that changes can be determined. Now it was only possible to find this road length and quality of one moment in time. Fourthly, a very suitable method for this topic of study has been developed while writing this research. AnySim is a cloud-based simulation software supporting multi-scale incorporating system dynamics modelling, agent-based modelling (ABM) and discrete-event simulation. By combining different methods (multi-method), this software would be suitable for including transportation networks and the effects on society on a geospatial scale.

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A

Census data 2011

The household survey that was given out to all inhabitants in Namibia in 2011 can be obtained from http://catalog.ihsn.org/index.php/catalog/3007.

Table A.1 below contains all variables deducted from the household survey.

Table A.1: The 89 variables divided over housing, mortality and person categories (Namibia Statistics Agency, 2013b)

Variables housing	**Variables housing**	**Variables mortality**	**Variables person**	**Variables person**
Region	Energy source: heating	Region	Region	ICT: newspaper
Constituency	Water source	Constituency	Constituency	ICT: internet
Urban/rural	Toilet facility	Urban/Rural	Urban/Rural	Attending ECD
Household type	Waste disposal	Household type	Household type	Literacy
Household serial number	Language spoken	Household serial number	Household serial number	Ever attended school
Housing type	Source of income	Death registered	Relationship	Highest grade completed
Tenure status	Own account agricultural activities	Death sex	Sex	Work
Dwelling units	Own agriculture: livestock	Death age	Age	Occupation
Sleeping rooms	Own agriculture: crop	Death cause	Usual member	Industry
Outer walls	Own agriculture: poultry	mwgt	Marital status	Main job
Roof	Livestock sector		Citizenship	Live births (female)
Floor	Crop sector		Birth Certificate	Live births (male)
Energy source: cooking	Poultry sector		Birth place	Children surviving (female)
Energy source: lighting	hwgt		Usual residence	Children surviving (male)
			Duration of residence	Children not alive (female)
			Previous residence	Children not alive (male)
			Mother alive	Age at first birth
			Father alive	Last live birth (month)
			Disability	Last live birth (year)
			Disability difficulties	Single/multiple birth
			ICT: none	Last live birth (females)
			ICT: radio	Last live birth (males)
			ICT: TV	Last live birth still alive (females)
			ICT: computer	Last live birth still alive (males)
			ICT: cell phone	pwgt
			ICT: telephone (fixed)	

B

Spatial data analysis

B.1. Road length data

Table B.1 shows the road length in old constituency division and new division. To determine the road length for the new division, the map by Immanuel (2013) and the QGIS overview of all constituency shapefiles plus the road network shapefile are used. The most right column shows the road density (RD) in km/km^2 of each constituency.

Table B.1: Old and new road length and road density according to new division, per constituency

OLD				NEW				
Region	**Constituency**	**Road length [km]**	**Surface [km2]**	**Region**	**Constituency**	**Road length [km]**	**Surface [km2]**	**RD [km/ km2]**
Erongo	Arandis	1935	13520	Erongo	Arandis	1935	13520	0,143
Erongo	Daures	3341	17787	Erongo	Daures	3341	17787	0,188
Erongo	Karibib	2047	14536	Erongo	Karibib	2047	14536	0,141
Erongo	Omaruru	1618	8432	Erongo	Omaruru	1618	8432	0,192
Erongo	Swakopmund	293	196	Erongo	Swakopmund	293	196	1,495
Erongo	Walvisbay Rural	1102	9150	Erongo	Walvisbay Rural	1102	9150	0,120
Erongo	Walvisbay Urban	153	19	Erongo	Walvisbay Urban	153	19	8,053
Hardap	Gibeon	6210	50365	Hardap	Aranos	2727,5	27908	0,145
Hardap	Mariental Rural	5455	41862	Hardap	Daweb	4140	37767	0,110
Hardap	Mariental Urban	574	5915	Hardap	Gibeon	2070	12591	0,164
Hardap	Rehoboth East	116	10959	Hardap	Mariental Rural	2727,5	13954	0,109
Hardap	Rehoboth Rural	1421	288	Hardap	Mariental Urban	574	5915	0,097
Hardap	Rehoboth West	166	325	Hardap	Rehoboth Urban East	116	288	0,403
Karas	Berseba	4239	31725	Hardap	Rehoboth Rural	1421	10959	0,130
Karas	Karas	4475	38329	Hardap	Rehoboth Urban West	166	325	0,511
Karas	Keetmans-hoop Rural	4144	37922	Karas	!Nami=Nus	2167	48271	0,045
Karas	Keetmans-hoop Urban	305	524	Karas	Berseba	4239	31725	0,134

Karas	Luderitz	2167	48271
Karas	Oranjemund	251	4623
Kavango	Kahenge	1916	8706
Kavango	Kapako	994	6189
Kavango	Mashare	1494	9143
Kavango	Mpungu	1062	8221
Kavango	Mukwe	1073	5541
Kavango	Ndiyona	1324	8083
Kavango	Rundu Rural	709	2683
Kavango	Rundu Urban	82	15
Khomas	Hakahana	128	52
Khomas	Katutura Central	14	2
Khomas	Katutura East	14	3
Khomas	Khomasdal North	91	26
Khomas	Soweto	7	2
Khomas	Wanaheda	52	19
Khomas	Windhoek East	416	167
Khomas	Windhoek Rural	11198	36469
Khomas	Windhoek West	556	209
Kunene	Epupa	2121	23617
Kunene	Kamanjab	4956	17131
Kunene	Khorixas	3099	21328
Kunene	Opuwo	2573	25823
Kunene	Outjo	981	7468
Kunene	Sesfontein	2964	20249
Ohang-wena	Eenhana	118	1272
Ohang-wena	Endola	146	490
Ohang-wena	Engela	188	295
Ohang-wena	Epembe	180	1810

Karas	Karasburg East	2983	25553	0,117
Karas	Karasburg West	1492	12777	0,117
Karas	Keetmans-hoop Rural	4144	37922	0,109
Karas	Keetmans-hoop Urban	305	524	0,582
Karas	Oranjemund	251	4623	0,082
Kavango East	Mashare	1494	9292	0,161
Kavango East	Mukwe	1073	5507	0,195
Kavango East	Ndiyona	662	6106	0,108
Kavango East	Ndonga Linena	662	2714	0,244
Kavango East	Rundu Rural	355	592	0,266
Kavango East	Rundu Urban	82	15	5,467
Kavango West	Kapako	99	1538	0,065
Kavango West	Mankumpi	1437	2195	0,393
Kavango West	Mpungu	708	8125	0,098
Kavango West	Musese	96	2195	0,065
Kavango West	Ncamagoro	895	4615	0,194
Kavango West	Ncuncuni	355	2091	0,266
Kavango West	Nkurenkuru	354	406	0,654
Kavango West	Tondoro	383	4390	0,153
Khomas	John Pandeni	7	2	3,500
Khomas	Katutura Central	14	2	7,000
Khomas	Katutura East	14	3	4,667
Khomas	Khomasdal	91	26	3,500
Khomas	Moses Garoeb	43	33	1,293
Khomas	Samora Machel	52	19	2,737
Khomas	Tobias Hainyeko	853	19	4,491
Khomas	Windhoek East	416	167	2,491
Khomas	Windhoek Rural	11198	36469	0,307
Khomas	Windhoek West	556	209	2,660

Ohang-wena	Ohangwena	105	170	Kunene	Epupa	2121	23617	0,090
Ohang-wena	Okongo	519	4601	Kunene	Kamanjab	4956	17130	0,289
Ohang-wena	Omun-daungilo	72	588	Kunene	Khorixas	3099	21328	0,145
Ohang-wena	Ondombe	89	723	Kunene	Opuwo Rural	2273	23671	0,096
Ohang-wena	Ongenga	46	317	Kunene	Opuwo Urban	300	2152	0,139
Ohang-wena	Oshikango	127	297	Kunene	Outjo	981	7468	0,131
Omaheke	Aminius	1387	12995	Kunene	Sesfontein	2964	20249	0,146
Omaheke	Gobabis	1286	5770	Ohangwena	Eenhana	100	1112	0,090
Omaheke	Kalahari	2322	12248	Ohangwena	Endola	117	328	0,356
Omaheke	Otjinene	1221	17462	Ohangwena	Engela	188	297	0,633
Omaheke	Otjombinde	791	18925	Ohangwena	Epembe	180	1810	0,099
Omaheke	Steinhausen	1910	17457	Ohangwena	Ohangwena M	105	170	0,618
Omusati	Anamulenge	101	354	Ohangwena	Okongo	346	3451	0,100
Omusati	Elim	89	444	Ohangwena	Omulonga	47	597	0,079
Omusati	Etayi	55	644	Ohangwena	Omun-daungilo	72	618	0,117
Omusati	Ogongo	109	807	Ohangwena	Ondobe	89	499	0,178
Omusati	Okahao	1525	14095	Ohangwena	Ongenga	46	320	0,144
Omusati	Okalongo	59	657	Ohangwena	Oshikango	127	261	0,487
Omusati	Onesi	113	602	Ohangwena	Oshikunde	173	1150	0,150
Omusati	Oshikuku	42	277	Omaheke	Aminius	1387	12995	0,107
Omusati	Outapi	168	986	Omaheke	Epukiro	814	10927	0,074
Omusati	Ruacana	856	5377	Omaheke	Gobabis	1286	5770	0,223
Omusati	Tsandi	169	2363	Omaheke	Kalahari	2322	12248	0,190
Oshana	Okaku	50	224	Omaheke	Okorukambe	1910	17457	0,109
Oshana	Okatana	117	426	Omaheke	Otjinene	407	6420	0,063
Oshana	Okatyali	3	558	Omaheke	Otjombinde	791	18924	0,042
Oshana	Ompundja	17	466	Omusati	Anamulenge	101	354	0,285
Oshana	Ondangwa	237	209	Omusati	Elim	89	444	0,200
Oshana	Ongwediva	184	222	Omusati	Etayi	55	644	0,085
Oshana	Oshakati East	136	187	Omusati	Ogongo	109	806	0,135
Oshana	Oshakati West	75	240	Omusati	Okahao	1220	9911	0,123
Oshana	Uukwiyu	31	300	Omusati	Okalongo	59	657	0,090
Oshana	Uuvudhiya	612	5825	Omusati	Onesi	113	602	0,188
Oshikoto	Engodi	502	7811	Omusati	Oshikuku	42	277	0,152
Oshikoto	Guinas	1618	10230	Omusati	Otamanzi	305	4184	0,073
Oshikoto	Okankolo	228	3552	Omusati	Outapi	168	985	0,171
Oshikoto	Olukonda	40	241	Omusati	Ruacana	856	5377	0,159
Oshikoto	Omuntele	129	1629	Omusati	Tsandi	169	2363	0,072
Oshikoto	Omuthiya-gwipundi	1746	13393	Oshana	Okaku	50	224	0,223
Oshikoto	Onayena	35	443	Oshana	Okatana	117	426	0,275
Oshikoto	Oniipa	195	372	Oshana	Okatyali	3	558	0,005
Oshikoto	Onyaanya	37	732	Oshana	Ompundja	17	466	0,036
Oshikoto	Tsumeb	197	271	Oshana	Ondangwa Rural	47	194	0,428

Otjozon-djupa	Grootfontein	1859	11279
Otjozon-djupa	Okahandja	1017	5857
Otjozon-djupa	Okakarara	1588	14644
Otjozon-djupa	Omatako	4326	24879
Otjozon-djupa	Otavi	1852	14243
Otjozon-djupa	Otjiwarongo	1347	5903
Otjozon-djupa	Tsumkwe	3795	28491
Zambezi	Kabe	479	2136
Zambezi	Katima Muliro Rural	416	1934
Zambezi	Katima Muliro Urban	66	32
Zambezi	Kongola	549	5086
Zambezi	Linyandi	440	3780
Zambezi	Sibinda	169	1699

Oshana	Ondangwa Urban	190	15	10,270
Oshana	Ongwediva	184	222	0,829
Oshana	Oshakati East	136	187	0,727
Oshana	Oshakati West	75	240	0,313
Oshana	Uukwiyu	31	300	0,103
Oshana	Uuvudhiya	612	5825	0,105
Oshikoto	Engodi	502	7811	0,064
Oshikoto	Guinas	1618	10230	0,158
Oshikoto	Nehale LyaMpingana		-	-
Oshikoto	Okankolo	228	3552	0,064
Oshikoto	Olukonda	40	241	0,166
Oshikoto	Omuntele	129	1629	0,079
Oshikoto	Omuthiya-gwipundi	1746	13393	0,130
Oshikoto	Onayena	35	443	0,079
Oshikoto	Oniipa	195	372	0,524
Oshikoto	Onyaanya	37	732	0,051
Oshikoto	Tsumeb	197	271	0,727
Otjozondjupa	Grootfontein	1859	11279	0,165
Otjozondjupa	Okahandja	1017	5857	0,174
Otjozondjupa	Okakarara	1588	14644	0,108
Otjozondjupa	Omatako	4326	24879	0,174
Otjozondjupa	Otavi	1852	14243	0,130
Otjozondjupa	Otjiwarongo	1347	5903	0,228
Otjozondjupa	Tsumkwe	3795	28491	0,133
Zambezi	Judea Lyaboloma	293	1890	0,155
Zambezi	Kabbe North	239	1068	0,299
Zambezi	Kabbe South	240	1068	0,150
Zambezi	Katima Muliro Rural	416	1935	0,215
Zambezi	Katima Muliro Urban	66	32	2,050
Zambezi	Kongola	549	5086	0,108
Zambezi	Linyanti	147	1890	0,078
Zambezi	Sibinda	169	1700	0,099

B.2. Education, health and employment data

Table B.2 shows the data which is used for the spatial data analysis in SPSS. The data on the three factors education, health and employment is merged into one table. Education data compasses the percentage that never attended school, the literacy rate and the number of educational facilities per constituency. The health data is the U5MR and the number of health facilities per constituency. It should be noted that the exact computation of an U5MR is more complex and takes more variances and errors into account. Alkema & New (2014) describe which formulas they use to acquire the U5MR, which is used by the UN. The UN value solely gives a national average and this research aims to make a distinction between the different constituencies to get insight in which constituencies perform relatively bad compared to the other constituencies. The U5MR in the table below is calculated by dividing the deaths of children of 0 until 5 (so 5 year old's not included) in the past 12 months (from household survey 2011) by the births in the past 12 months (same survey). This results in a unit is than deaths per 1000 live births. The average of all constituencies is 71 where the UN estimated an average of 52 in 2011 (UN Inter-agency Group for Child Mortality Estimation, 2018). This is a big difference and therefore the average U5MR as calculated for this research is not used to compare to other countries but solely to make a distinction between the constituencies. The last column shows the unemployment rate per constituency.

Table B.2: Data on education, health and employment

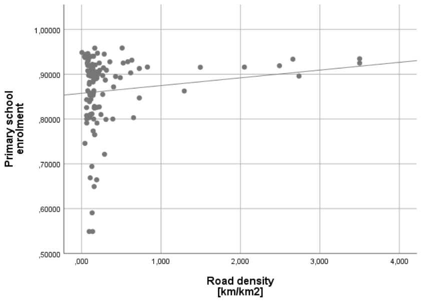
Region	**Constituency**	**Primary school enrolment rate**	**School facilities surface**	**U5MR**	**Health facilities surface**	**Unemployment rate**
Erongo	Arandis	0,912	0,0004	45,1	0,0002	0,276
Erongo	Daures	0,905	0,0007	74,5	0,0003	0,436
Erongo	Karibib	0,906	0,0005	66,5	0,0004	0,411
Erongo	Omaruru	0,892	0,0009	52,2	0,0004	0,337
Erongo	Swakopmund	0,916	0,0561	44,3	0,0153	0,256
Erongo	Walvisbay Rural	0,915	0,0001	43,3	0,0000	0,318
Erongo	Walvisbay Urban	0,919	0,4737	22,1	0,3158	0,268
Hardap	Aranos	0,853	0,0003	43,5	0,0001	0,352
Hardap	Daweb	0,896	0,0001	200,0	0,0001	0,307
Hardap	Gibeon	0,896	0,0006	92,7	0,0001	0,429
Hardap	Mariental Rural	0,853	0,0004	71,4	0,0002	0,338
Hardap	Mariental Urban	0,878	0,0010	61,3	0,0003	0,369
Hardap	Rehoboth Urban East	0,872	0,0278	62,9	0,0069	0,384
Hardap	Rehoboth Rural	0,918	0,0016	84,7	0,0004	0,308
Hardap	Rehoboth Urban West	0,959	0,0123	28,2	0,0000	0,300
Karas	!Nami=Nus	0,937	0,0001	39,1	0,0001	0,282
Karas	Berseba	0,896	0,0005	94,5	0,0001	0,433
Karas	Karasburg East	0,900	0,0003	56,0	0,0002	0,398
Karas	Karasburg West	0,900	0,0002	28,8	0,0002	0,289
Karas	Keetmanshoop Rural	0,900	0,0001	113,6	0,0001	0,301
Karas	Keetmanshoop Urban	0,928	0,0172	53,7	0,0057	0,348
Karas	Oranjemund	0,930	0,0004	23,3	0,0006	0,245
Kavango East	Mashare	0,828	0,0031	96,7	0,0006	0,538
Kavango East	Mukwe	0,826	0,0074	199,3	0,0020	0,364
Kavango East	Ndiyona	0,810	0,0033	124,2	0,0007	0,446
Kavango East	Ndonga Linena	0,810	0,0055	63,0	0,0011	0,436
Kavango East	Rundu Rural	0,855	0,0180	101,0	0,0034	0,533
Kavango East	Rundu Urban	0,925	0,2667	75,6	0,2000	0,629

Kavango West	Kapako	0,791	0,0065	84,3	0,0020	0,570
Kavango West	Mankumpi	0,800	0,0024	101,6	0,0005	0,420
Kavango West	Mpungu	0,803	0,0049	84,7	0,0006	0,275
Kavango West	Musese	0,800	0,0150	187,0	0,0018	0,488
Kavango West	Ncamagoro	0,791	0,0052	99,2	0,0002	0,523
Kavango West	Ncuncuni	0,897	0,0113	81,1	0,0033	0,349
Kavango West	Nkurenkuru	0,803	0,0295	144,0	0,0025	0,367
Kavango West	Tondoro	0,800	0,0057	66,3	0,0009	0,377
Khomas	John Pandeni	0,935	0,5000	28,3	0,0000	0,324
Khomas	Katutura Central	0,892	2,5000	36,6	1,5000	0,365
Khomas	Katutura East	0,896	3,6667	36,1	0,3333	0,337
Khomas	Khomasdal	0,925	0,3462	22,8	0,1538	0,245
Khomas	Moses Garoeb	0,863	0,0000	50,4	0,0303	0,410
Khomas	Samora Machel	0,896	0,0526	45,5	0,2105	0,374
Khomas	Tobias Hainyeko	0,880	0,0000	54,3	0,0526	0,401
Khomas	Windhoek East	0,919	0,0659	21,2	0,0060	0,070
Khomas	Windhoek Rural	0,799	0,0004	66,9	0,0001	0,234
Khomas	Windhoek West	0,934	0,0813	23,4	0,0000	0,132
Kunene	Epupa	0,254	0,0009	37,7	0,0003	0,191
Kunene	Kamanjab	0,721	0,0002	82,1	0,0001	0,238
Kunene	Khorixas	0,883	0,0005	177,4	0,0002	0,465
Kunene	Opuwo Rural	0,549	0,0006	53,8	0,0002	0,279
Kunene	Opuwo Urban	0,549	0,0051	60,5	0,0009	0,498
Kunene	Outjo	0,811	0,0007	130,9	0,0003	0,345
Kunene	Sesfontein	0,773	0,0003	84,1	0,0001	0,462
Ohangwena	Eenhana	0,897	0,0225	55,6	0,0018	0,432
Ohangwena	Endola	0,928	0,0457	68,1	0,0091	0,445
Ohangwena	Engela	0,931	0,0539	56,5	0,0067	0,434
Ohangwena	Epembe	0,839	0,0133	60,5	0,0011	0,368
Ohangwena	Ohangwena M	0,903	0,0647	80,9	0,0176	0,490
Ohangwena	Okongo	0,858	0,0052	81,2	0,0009	0,323
Ohangwena	Omulonga	0,908	0,0369	77,5	0,0050	0,417
Ohangwena	Omundaungilo	0,844	0,0146	85,4	0,0049	0,419
Ohangwena	Ondobe	0,890	0,0421	73,6	0,0040	0,469
Ohangwena	Ongenga	0,940	0,0594	63,0	0,0094	0,417
Ohangwena	Oshikango	0,892	0,0613	81,0	0,0077	0,476
Ohangwena	Oshikunde	0,858	0,0122	54,0	0,0000	0,338
Omaheke	Aminius	0,808	0,0006	49,0	0,0003	0,473
Omaheke	Epukiro	0,803	0,0004	41,7	0,0001	0,487
Omaheke	Gobabis	0,827	0,0016	82,1	0,0005	0,403
Omaheke	Kalahari	0,664	0,0006	37,6	0,0001	0,308
Omaheke	Okorukambe	0,669	0,0002	77,7	0,0002	0,287
Omaheke	Otjinene	0,825	0,0006	62,2	0,0002	0,489
Omaheke	Otjombinde	0,746	0,0002	48,8	0,0001	0,357
Omusati	Anamulenge	0,945	0,0508	56,7	0,0056	0,374
Omusati	Elim	0,947	0,0428	43,3	0,0068	0,329
Omusati	Etayi	0,933	0,0435	63,3	0,0062	0,451
Omusati	Ogongo	0,922	0,0248	47,5	0,0050	0,355
Omusati	Okahao	0,903	0,0023	49,2	0,0004	0,362
Omusati	Okalongo	0,905	0,0487	71,2	0,0091	0,480
Omusati	Onesi	0,891	0,0233	87,0	0,0066	0,546
Omusati	Oshikuku	0,940	0,0433	51,7	0,0108	0,418
Omusati	Otamanzi	0,926	0,0022	64,0	0,0007	0,478

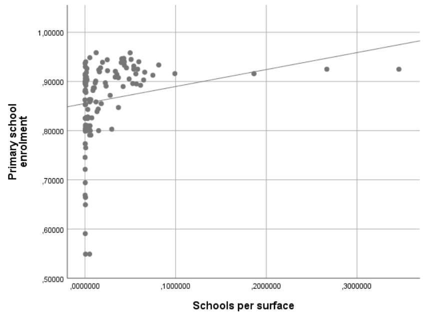
Omusati	Outapi	0,921	0,0335	63,6	0,0041	0,401
Omusati	Ruacana	0,825	0,0030	69,8	0,0006	0,355
Omusati	Tsandi	0,924	0,0152	68,2	0,0013	0,452
Oshana	Okaku	0,925	0,0580	62,6	0,0045	0,354
Oshana	Okatana	0,914	0,0352	39,6	0,0047	0,472
Oshana	Okatyali	0,948	0,0054	28,0	0,0000	0,394
Oshana	Ompundja	0,939	0,0193	25,0	0,0000	0,318
Oshana	Ondangwa Rural	0,895	0,0567	67,3	0,0052	0,371
Oshana	Ondangwa Urban	0,895	0,6667	80,0	0,0667	0,382
Oshana	Ongwediva	0,916	0,0991	63,9	0,0135	0,314
Oshana	Oshakati East	0,913	0,0749	66,6	0,0160	0,372
Oshana	Oshakati West	0,909	0,0333	33,1	0,0042	0,446
Oshana	Uukwiyu	0,938	0,0400	64,6	0,0067	0,297
Oshana	Uuvudhiya	0,940	0,0009	92,8	0,0002	0,291
Oshikoto	Engodi	0,808	0,0019	59,1	0,0001	0,341
Oshikoto	Guinas	0,649	0,0005	63,6	0,0002	0,381
Oshikoto	Okankolo	0,843	0,0031	54,6	0,0008	0,378
Oshikoto	Olukonda	0,958	0,0498	56,5	0,0083	0,322
Oshikoto	Omuntele	0,920	0,0160	80,8	0,0025	0,361
Oshikoto	Omuthiyag-wipundi	0,903	0,0014	50,7	0,0002	0,361
Oshikoto	Onayena	0,946	0,0406	80,0	0,0023	0,362
Oshikoto	Oniipa	0,925	0,0538	52,5	0,0054	0,385
Oshikoto	Onyaanya	0,944	0,0246	48,2	0,0000	0,431
Oshikoto	Tsumeb	0,847	0,0369	49,5	0,0148	0,349
Otjozondjupa	Grootfontein	0,765	0,0008	45,1	0,0003	0,308
Otjozondjupa	Okahandja	0,898	0,0010	68,1	0,0003	0,397
Otjozondjupa	Okakarara	0,853	0,0006	69,6	0,0004	0,468
Otjozondjupa	Omatako	0,825	0,0002	29,2	0,0001	0,224
Otjozondjupa	Otavi	0,694	0,0004	84,5	0,0001	0,308
Otjozondjupa	Otjiwarongo	0,909	0,0017	40,1	0,0005	0,400
Otjozondjupa	Tsumkwe	0,591	0,0004	86,6	0,0001	0,521
Zambezi	Judea Lyaboloma	0,863	0,0063	110,5	0,0016	0,205
Zambezi	Kabbe North	0,887	0,0094	59,2	0,0028	0,377
Zambezi	Kabbe South	0,887	0,0103	98,1	0,0037	0,128
Zambezi	Katima Muliro Rural	0,901	0,0119	117,0	0,0031	0,343
Zambezi	Katima Muliro Urban	0,916	0,1863	66,5	0,0311	0,506
Zambezi	Kongola	0,808	0,0010	105,3	0,0002	0,365
Zambezi	Linyanti	0,863	0,0048	314,7	0,0011	0,345
Zambezi	Sibinda	0,882	0,0088	102,6	0,0024	0,428

B.3. Assumptions check for multiple regression analysis

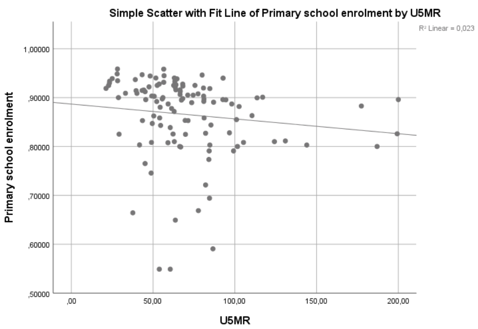
Education



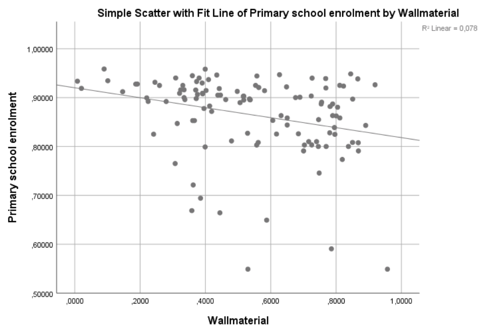
(a) Road density and PSE



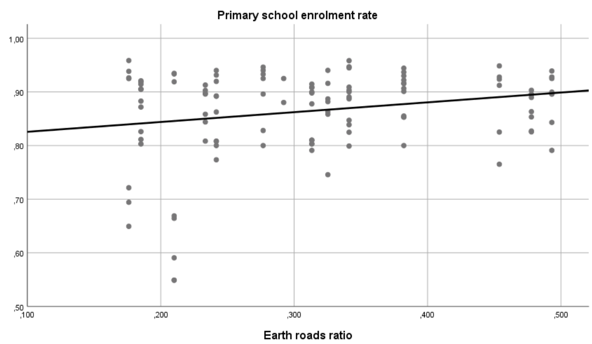
(b) Facilities per surface and PSE



(c) U5MR and PSE

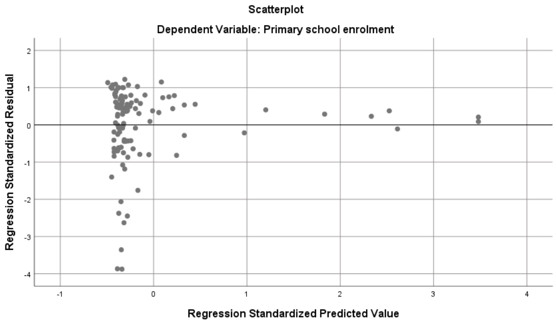


(d) Material of walls and PSE

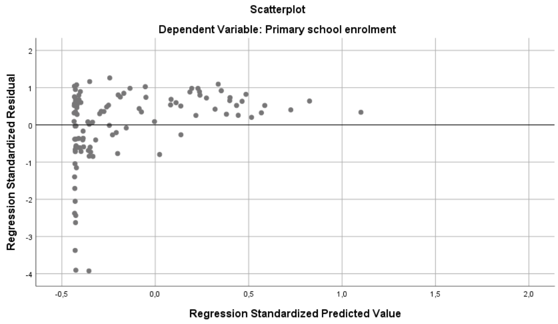


(e) Earth road ratio and PSE

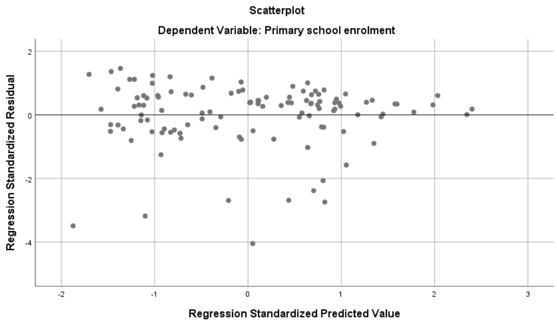
Figure B.1: Scatter-plots of linear relations between RD, facilities per surface, U5MR, wall material and earth road ratio and PSE



(a) Road density and PSE

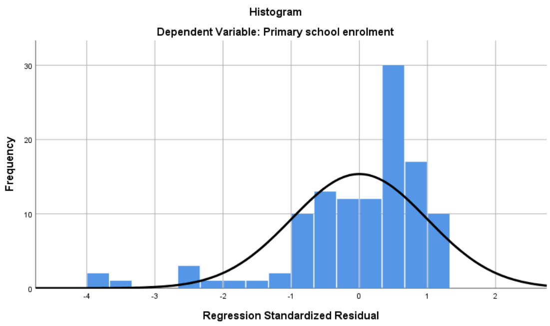


(b) School facilities per surface and PSE

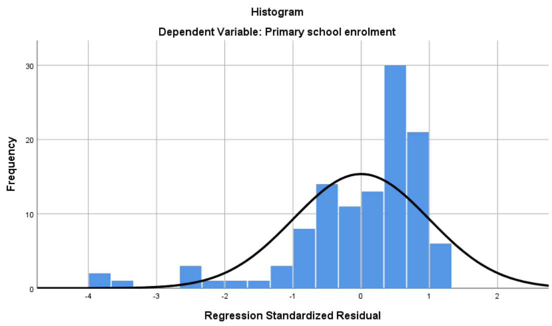


(c) Wall material and PSE

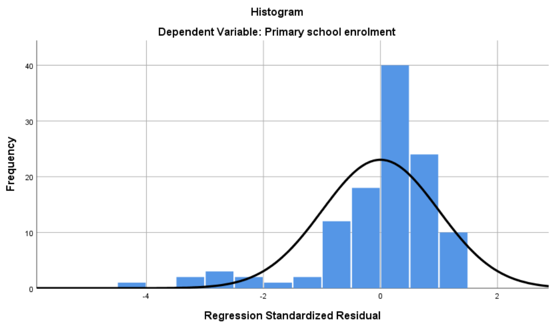
Figure B.2: Scatter-plot of standardised predicted value and residuals of road density, education facilities per surface and walls material with primary school enrolment



(a) Road density and PSE



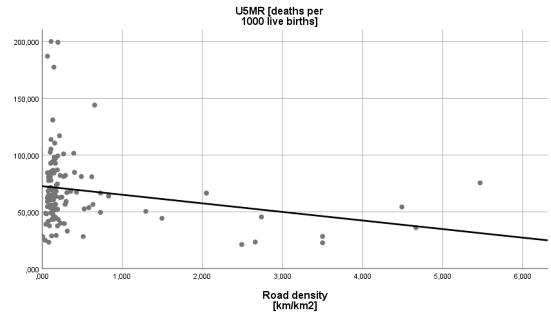
(b) School facilities per surface and PSE



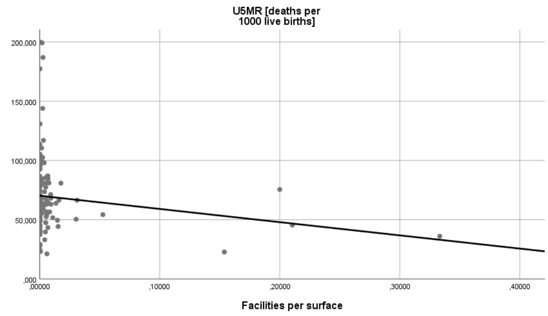
(c) Wall material and PSE

Figure B.3: Histograms and normal distribution of the residuals of road density and facilities per surface with primary school enrolment

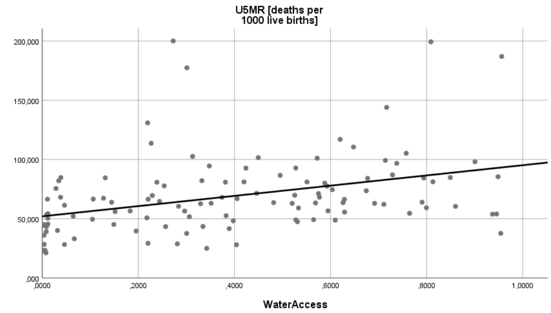
Health



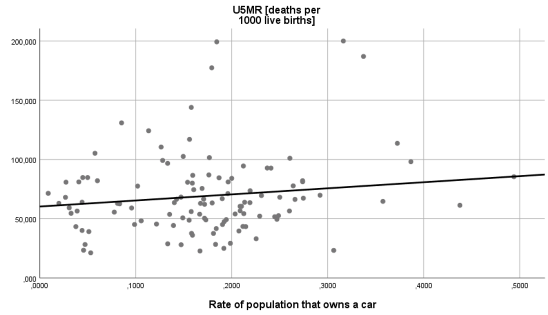
(a) RD and U5MR



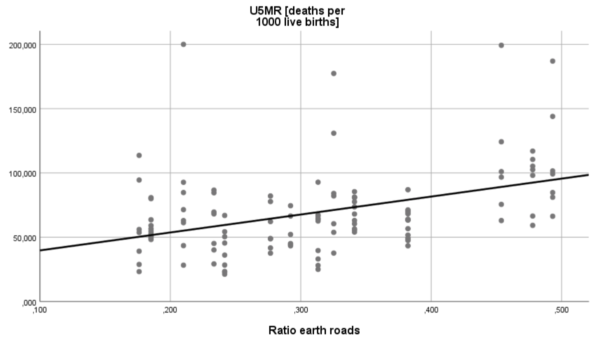
(b) Facilities per surface and U5MR



(c) Safe water access and U5MR

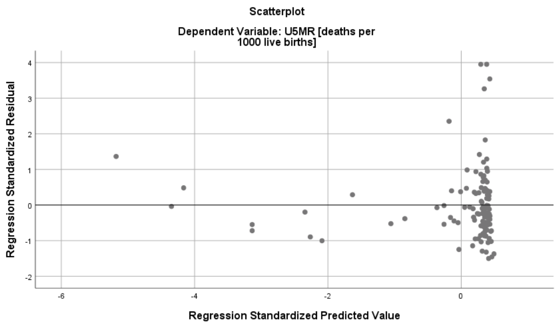


(d) Car ownership and U5MR

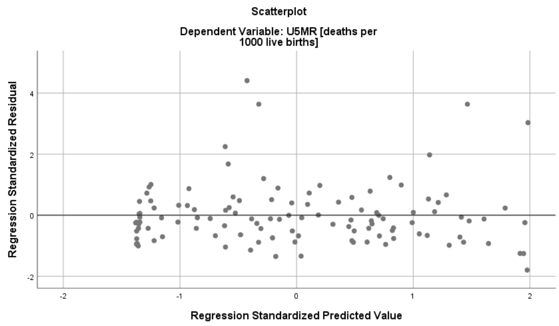


(e) Earth roads ratio and U5MR

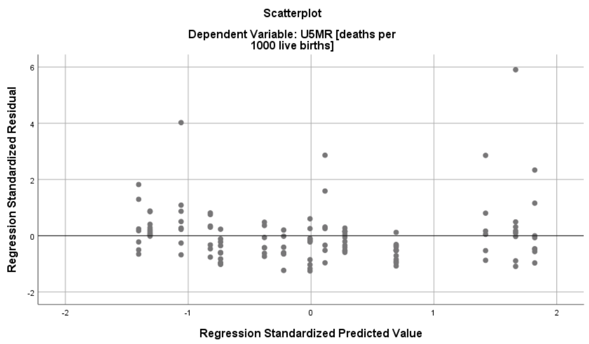
Figure B.4: Linear relations between the four different independent variables and U5MR



(a) Road density and U5MR

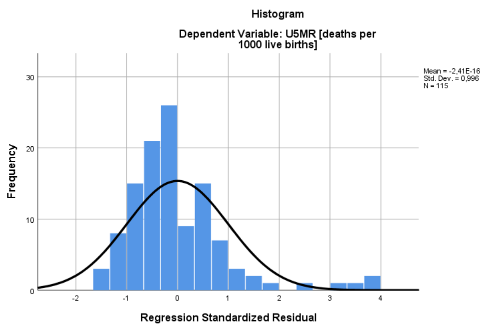


(b) Safe water access and U5MR

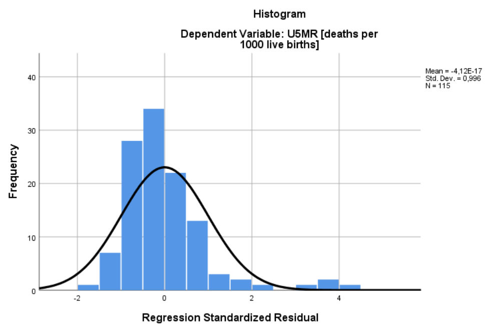


(c) Earth roads ratio and U5MR

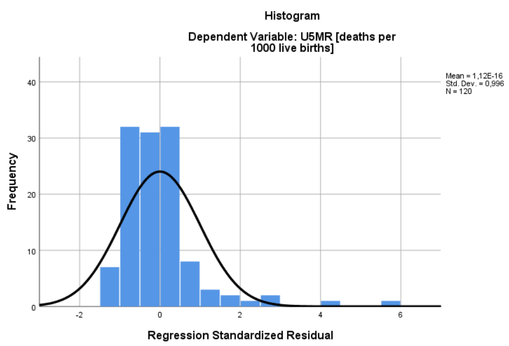
Figure B.5: Scatter-plot of standardised predicted value and residuals of road density, safe water access and earth roads ratio with U5MR



(a) Road density and U5MR



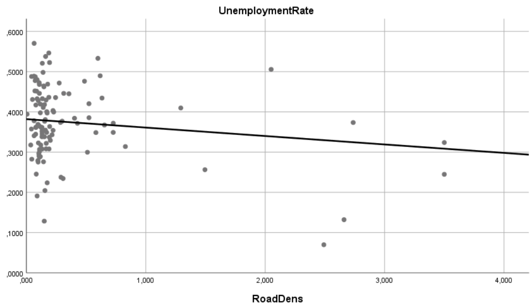
(b) Safe water access and U5MR



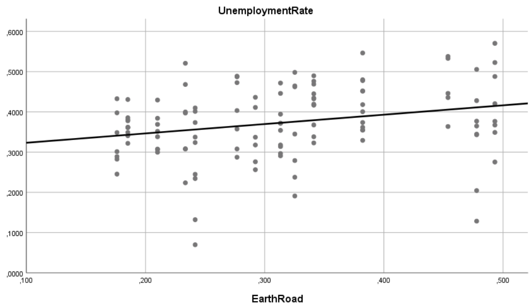
(c) Earth roads ratio and U5MR

Figure B.6: Histogram and normal distribution of standardised predicted values and residuals of independent variables and U5MR

Employment

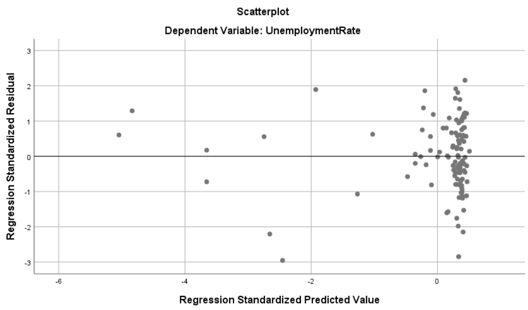


(a) Road density and unemployment rate

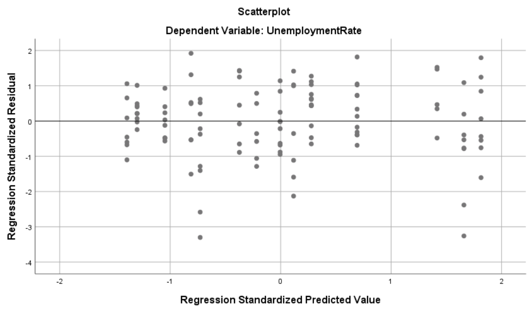


(b) Earth roads ratio and unemployment rate

Figure B.7: Linear regression of road density and earth roads ratio and unemployment rate

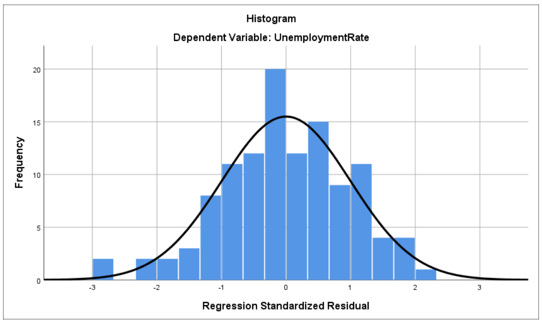


(a) Road density and unemployment rate

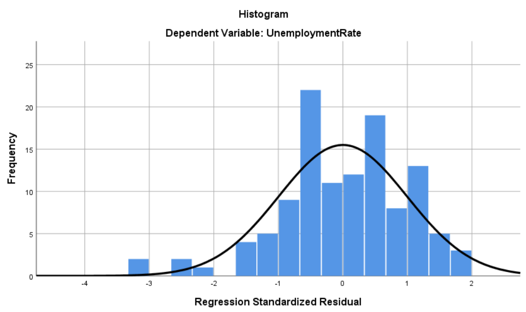


(b) Earth roads ratio and unemployment rate

Figure B.8: Standardised earth roads ratio and unemployment rate



(a) Road density and unemployment rate



(b) Earth roads ratio and unemployment rate

Figure B.9: Histogram and normal distribution of errors of road density and earth road ratio and unemployment rate

C

Subscript (mapping) in Vensim

Subscripting with regions and constituencies

- **Step 1: Constituency subscript**
  - In Vensim: Click subscript, click 'New..' (or 'Edit..' when it already exists), enter name of subscript and add equation: GET XLS SUBSCRIPT(*'name of excel data file', 'name of sheet', 'name range of constituencies', ''*)
  - This will load all the constituencies into the Vensim model within the subscript *constituencies.*
  - Example: GET XLS SUBSCRIPT('?Population.xlsx', 'Population density' , 'A2' , 'A121' , '')
- **Step 2: Creating subranges for constituencies in each region**
  - Make sure the constituencies in the Excel file are sorted by region. For each region, we have to define in Vensim which constituencies belong to it.
  - In Vensim: Click subscript, click 'New..' (or 'Edit..' when it already exists), enter the name of region, and add equation: GET XLS SUBSCRIPT(*'name of excel data file', 'name of sheet', 'name range of constituencies belong to that region', ''*).
  - Vensim now automatically creates a subrange containing the constituencies in the selected cells. Repeat this process for each region.
  - Example: GET XLS SUBSCRIPT('?Population', 'Health total' , 'J2' , 'J15' , 'regions')
- **Step 3: Mapping the regions onto the subranges**
  - The regions are now defined as subranges of constituency. The advantage of having this structure is that a value for a region can be used for all constituencies within that region. Therefore, we must create another subscript range called regions.
  - The regions are retrieved from the Excel-sheet and they can be mapped onto the subranges of constituencies as follows: GET XLS SUBSCRIPT(*'name of excel data file', 'name of sheet', 'name range of constituencies belong to that region', 'specify a prefix'*) -> (subscript countries: 'region subrange 1', 'region subrange 2', '...')
  - Example: GET XLS SUBSCRIPT('?Population', 'Health total' , 'J2' , 'J15' , 'regions') -> (constituencies: Erongo, Hardap, Karas, KavangoEast, KavangoWest, Khomas, Kunene, Ohangwena, Omaheke, Omusati, Oshana, Oshikoto, Otjozondjupa, Zambezi)
- **Step 4: Defining the variables**
  - To define a variable for all constituencies, use subscript range [constituencies] and to define a variable for all regions [regions]

D

Performance constituencies

Constituency	Road density	Education	Health	Employment
Arandis	0,143	0,912	45,1	0,276
Daures	0,188	0,905	74,5	0,436
Karibib	0,141	0,906	66,5	0,411
Omaruru	0,192	0,892	52,2	0,337
Swakopmund	1,495	0,916	44,3	0,256
Walvisbay Rural	0,120	0,915	43,3	0,318
Walvisbay Urban	8,053	0,919	22,1	0,268
Aranos	0,130	0,853	43,5	0,352
Daweb	0,110	0,896	200,0	0,307
Gibeon	0,164	0,896	92,7	0,429
Mariental Rural	0,130	0,853	71,4	0,338
Mariental Urban	0,097	0,878	61,3	0,369
Rehoboth Urban East	0,403	0,872	62,9	0,384
Rehoboth Rural	0,130	0,918	84,7	0,308
Rehoboth Urban West	0,511	0,959	28,2	0,300
!Nami=Nus	0,045	0,937	39,1	0,282
Berseba	0,134	0,896	94,5	0,433
Karasburg East	0,117	0,900	56,0	0,398
Karasburg West	0,117	0,900	28,8	0,289
Keetmanshoop Rural	0,109	0,900	113,6	0,301
Keetmanshoop Urban	0,582	0,928	53,7	0,348
Oranjemund	0,082	0,930	23,3	0,245
Mashare	0,161	0,828	96,7	0,538
Mukwe	0,195	0,826	199,3	0,364
Ndiyona	0,108	0,810	124,2	0,446
Ndonga Linena	0,244	0,810	63,0	0,436
Rundu Rural	0,599	0,855	101,0	0,533
Rundu Urban	5,467	0,925	75,6	0,629
Kapako	0,065	0,791	84,3	0,570
Mankumpi	0,524	0,800	101,6	0,420
Mpungu	0,098	0,803	84,7	0,275
Musese	0,044	0,800	187,0	0,488

Constituency	Road density	Education	Health	Employment
Ncamagoro	0,194	0,791	99,2	0,523
Ncuncuni	0,170	0,897	81,1	0,349
Nkurenkuru	0,654	0,803	144,0	0,367
Tondoro	0,153	0,8	66,3	0,377
John Pandeni	3,500	0,93452	28,3	0,324
Katutura Central	7,000	0,89159	36,6	0,365
Katutura East	4,667	0,89639	36,1	0,337
Khomasdal	3,500	0,9249	22,8	0,245
Moses Garoeb	1,293	0,86254	50,4	0,410
Samora Machel	2,737	0,89588	45,5	0,374
Tobias Hainyeko	4,491	0,8803	54,3	0,401
Windhoek East	2,491	0,9189	21,2	0,070
Windhoek Rural	0,307	0,79908	66,9	0,234
Windhoek West	2,660	0,93356	23,4	0,132
Epupa	0,090	0,25422	37,7	0,191
Kamanjab	0,289	0,72133	82,1	0,238
Khorixas	0,145	0,88284	177,4	0,465
Opuwo Rural	0,096	0,549	53,8	0,279
Opuwo Urban	0,139	0,549	60,5	0,498
Outjo	0,131	0,81137	130,9	0,345
Sesfontein	0,146	0,77344	84,1	0,462
Eenhana	0,090	0,8973	55,6	0,432
Endola	0,356	0,92767	68,1	0,445
Engela	0,633	0,93137	56,5	0,434
Epembe	0,099	0,83875	60,5	0,368
Ohangwena M	0,618	0,90304	80,9	0,490
Okongo	0,100	0,8584	81,2	0,323
Omulonga	0,079	0,90779	77,5	0,417
Omundaungilo	0,117	0,84399	85,4	0,419
Ondobe	0,178	0,88972	73,6	0,469
Ongenga	0,144	0,94017	63,0	0,417
Oshikango	0,487	0,89232	81,0	0,476

Figure D.1: Constituency performance

Constituency	Road density	Education	Health	Employment
Oshikunde	0,150	0,858	54,0	0,338
Aminius	0,107	0,808	49,0	0,473
Epukiro	0,074	0,803	41,7	0,487
Gobabis	0,223	0,827	82,1	0,403
Kalahari	0,190	0,664	37,6	0,308
Okorukambe	0,109	0,669	77,7	0,287
Otjinene	0,063	0,825	62,2	0,489
Otjombinde	0,042	0,746	48,8	0,357
Anamulenge	0,285	0,945	56,7	0,374
Elim	0,200	0,947	43,3	0,329
Etayi	0,085	0,933	63,3	0,451
Ogongo	0,135	0,922	47,5	0,355
Okahao	0,123	0,903	49,2	0,362
Okalongo	0,090	0,905	71,2	0,480
Onesi	0,188	0,891	87,0	0,546
Oshikuku	0,152	0,940	51,7	0,418
Otamanzi	0,073	0,926	64,0	0,478
Outapi	0,171	0,921	63,6	0,401
Ruacana	0,159	0,825	69,8	0,355
Tsandi	0,072	0,924	68,2	0,452
Okaku	0,223	0,925	62,6	0,354
Okatana	0,275	0,914	39,6	0,472
Okatyali	0,005	0,948	28,0	0,394
Ompundja	0,036	0,939	25,0	0,318
Ondangwa Rural	0,428	0,895	67,3	0,371
Ondangwa Urban	10,270	0,895	80,0	0,382
Ongwediva	0,829	0,916	63,9	0,314
Oshakati East	0,727	0,913	66,6	0,372
Oshakati West	0,313	0,909	33,1	0,446
Uukwiyu	0,103	0,938	64,6	0,297
Uuvudhiya	0,105	0,940	92,8	0,291
Engodi	0,064	0,808	59,1	0,341

Constituency	Road density	Education	Health	Employment
Guinas	0,158	0,649	63,6	0,381
Okankolo	0,064	0,843	54,6	0,378
Olukonda	0,166	0,958	56,5	0,322
Omuntele	0,079	0,920	80,8	0,361
Omuthiyagwipundi	0,130	0,903	50,7	0,361
Onayena	0,079	0,946	80,0	0,362
Oniipa	0,524	0,925	52,5	0,385
Onyaanya	0,051	0,944	48,2	0,431
Tsumeb	0,727	0,847	49,5	0,349
Grootfontein	0,165	0,765	45,1	0,308
Okahandja	0,174	0,898	68,1	0,397
Okakarara	0,108	0,853	69,6	0,468
Omatako	0,174	0,825	29,2	0,224
Otavi	0,130	0,694	84,5	0,308
Otjiwarongo	0,228	0,909	40,1	0,400
Tsumkwe	0,133	0,591	86,6	0,521
Judea Lyaboloma	0,155	0,863	110,5	0,205
Kabbe North	0,299	0,887	59,2	0,377
Kabbe South	0,150	0,887	98,1	0,128
Katima Muliro Rural	0,215	0,901	117,0	0,343
Katima Muliro Urban	2,050	0,916	66,5	0,506
Kongola	0,108	0,808	105,3	0,365
Linyanti	0,078	0,863	314,7	0,345
Sibinda	0,099	0,882	102,6	0,428

Figure D.2: Constituency performance

E
Scientific Paper

The effects of an improved road network on social factors in developing countries - A case study of Namibia

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***Abstract*—This research examined the effect of an improved road network on the factors economic growth, road safety, emissions, education, health, employment and tourism in developing countries. A case study is conducted on the country Namibia in Southern Africa. A System Dynamics (SD) model is developed to assess the effects of future scenarios in terms of road infrastructure on the mentioned factors. The SD model is based on a literature study on developing countries in general and a data analysis on Namibia in specific. The identified scenarios are (i) Namibia becoming the logistics hub of Southern Africa by 2022 and (ii) enhance tourism by improving road infrastructure between the major tourism attractions. Both scenarios lead to improvements in health, tourism and employment. The primary school enrolment rates remained the same over time for both scenarios. Road safety increases for both scenarios due to upgrades to bitumen, but the extent to which it increases depends on the extra measures that are taken with regards to road safety. It can be increased more by campaigns or more controls. Emissions go up in both scenarios, because emissions are a direct result of constructing and upgrading roads. The tourism scenario attracts more tourists because the roads between the major attractions are upgraded to bitumen. Both scenarios are realistic and might happen in the future. The scenarios can and might be combined.**

***Keywords*—Road infrastructure, developing countries, economic growth, System Dynamics, education, health, employment, tourism**

I. Introduction

As of today, 783 million people live below the international poverty line of US$1.90 a day and 815 million people are undernourished (United Nations, 2018c). These numbers on poverty and hunger are only two of the seventeen Sustainable Development Goals (SDGs) as deployed by the United Nations (UN) in 2015. The SDGs aim to end poverty, protect the planet and ensure that all people enjoy peace and prosperity (United Nations, 2018b). One of these SDGs focuses on industries, innovation and infrastructure, where infrastructure provides the basic physical facilities essential to business and society (United Nations, 2016).

Different researches acknowledge the effect of physical infrastructure on the economic growth and the reduction of poverty (Esfahani & Ramírez, 2003; Jimenez, 1995; Yoshino & Nakahigashi, 2000). Due to limited expenditure, big investments such as infrastructure investments are fundamental and crucial for developing countries. More insight in the exact effects that investing in transport infrastructure has on socioeconomic factors within a country is needed. There is a limited amount of research on the effects of transport infrastructure in developing countries on these factors. Also, most researches have investigated one single effect of transport infrastructures or imposed challenges of each separate factor as a static relationship. Since most governments of developing countries only have a limited expenditure and have to make fundamental choices with regards to investments in certain sectors, it is very important to be able to get more insights in these effects. Therefore, the aim of this research is *to develop a method for investigating the effects of road infrastructure on road safety, emissions, economic growth, health, education, tourism and employment and secondly, it applies the research plan to Namibia*. Namibia is a developing country in Southern Africa and is part of the Southern African Development Community (SADC). National plans emphasise on the ambition of becoming the logistics hub of the SADC by 2022. To achieve this ambition and to grow as a country in general, large amounts of money are invested in the road infrastructure in Namibia.

II. Research Approach

The research is carried out based on a Systems Engineering (SE) methodology, which is a discipline or a way of thinking that manages problem solving processes in the context of socio-technical questions and which looks at a problem in its entirety and aims to enable the realisation of successful systems (INCOSE, 2007; Züst & Troxler, 2006). Using Systems Engineering as a methodology for this research means that the study is divided into three phases: definition, development and deployment. The definition phase includes (i) a literature study in which the relations between road infrastructure and economic growth, road safety, emissions, education, health, employment and tourism are identified; (ii) a country analysis of the country Namibia in terms of socio-demographic status and transport infrastructure situation; (iii) a spatial data analysis in which the relations between variables of which data is available are tested and (iv) explanations behind the data that is used. Phase two describes the model development with the help of System Dynamics (SD). The model is developed based on a data- and theory-rich modelling approach, which implies that

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the used data is embedded in a proper theoretical framework in which the data can provide useful insights and theory can explain relations and substantiate assumptions. Phase three identifies two possible future scenarios and uses the model to analyse the effects on the factors of these scenarios.

III. Literature Review

A deep-dive in literature aims at investigating scientific literature on the topic of this research. It conducts a literature study to examine (i) how transport infrastructure enhances sustainable development, (ii) the most important (underlying) relations between road infrastructure and economic growth and (iii) which method is most suitable for this research.

The eighth SDG says to ”promote sustained, inclusive and sustainable economic growth, full and productive employment and decent work for all” (United Nations, 2018a). According to Fuente (2010); Melo, Graham, and Brage-Ardao (2013); Pradhan and Bagchi (2013) transport infrastructure positively influences economic growth. The magnitude of the effect is higher in developing countries accotding to many researchers (Candelon, Colletaz, & Hurlin, 2013; Fuente, 2010; Lakhera, 2016). There is usually a lot to gain and influence in developing countries with regards to transport, transport policies and transport investments. Hence, this research focuses on the transport infrastructure in developing countries. Transport infrastructure affects more factors than economic growth. A theoretical framework compassing all relations found in this literature study is shown in figure 1. A bidirectional relation

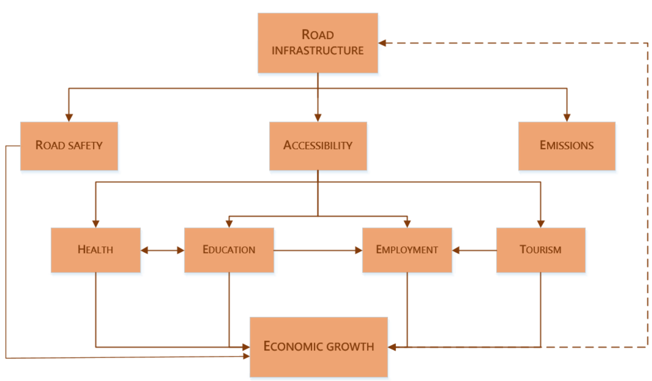

Fig. 1. Theoretical framework based on literature study

between road infrastructure and economic growth is identified. This research used the ’broader consequences of transport capital’ approach Lakshmanan (2011) in the sense of looking at socio-economic factors underlying the relation between road infrastructure and economic growth. This study is on performed on a highly aggregated level, which means that not all underlying mechanisms and factors are taken into account and the relation between road infrastructure and economic growth remains highly aggregated as well. The influence of economic growth on transport infrastructure is not uniformly determined in research. The relation is dependent on both the context and the type of infrastructure. However, differences among researchers occur in terms of the existence of an influence of the Gross Domestic Product (GDP) on road infrastructure.

Road safety is a major issue with regards to road infrastructure, mainly in developing countries. Predictions are that the number of road crashes and the number of road traffic deaths will increase in the coming years. Road traffic injuries cost the governments between 1% and 3% of their gross national product on a yearly basis. Besides, road infrastructure investment (currently) inevitably leads to more emissions. Overall, the materials seem to cause the largest amount of emissions (Hanson & Noland, 2015). Most of the discussed researches on these topics focus on how to reduce the emissions. The suggestions that come forward mostly bring extra costs and some of them are not necessarily feasible, but there are opportunities for certain cases to reduce emissions of the overall road construction and usage. The actual total emissions highly depend on what the researcher includes in the estimations.

The general accessibility increases through improved road infrastructure. General accessibility enhances tourism Khadaroo and Seetanah (2008), health (Airey, 1991; Donnell O’, 2007; Fedderke & Bogetić, 2009; Sperling, 2002), education (Brenneman & Kerf, 2002; Porter, 2010; Siddhu, 2011; Vasconcellos, 1997) and employment (Akinbobola & Saibu, 2004; Sperling, 2002). Improvement of each of these factors has a significant positive effect on a country’s economic growth according to different researchers. Some of the factors appear to have a reciprocal relationship; a higher quality of education generally leads to a higher employment rate (Boccanfuso, Larouche, & Trandafir, 2015; Guarcello et al., 2008), tourism - in most cases - leads to more jobs hence higher employment rates (Lee, Hampton, & Jeyacheya, 2015; Mbaiwa, 2017) and health and education have a bidirectional relationship (Glewwe, 2005; Gwatkin et al., 2007).

Lastly, the literature study examined the most suitable method to capture spatial dynamics as come forward in this study. This appears to be System Dynamics (SD) which is ”a method to describe, model, simulate and analyze dynamically complex issues and/or systems in terms of the processes, information, organizational boundaries and strategies” (Pruyt, 2013). The fundamental principle of SD is that structure determines behaviour (Brailsford, 2008). By allowing for estimating effects of a policy measure on a system - in particular a country - and by giving insight in (long term) results and effects of a policy measure such as road infrastructure investment on a system or country, this approach is very suitable for the spatial transportation dynamics as in this study.

IV. Country Analysis

In order to get insights in and an overview of the country Namibia, the socio-demographic status and the transport infrastructure situation are investigated. To do so, both data and sources such as government websites and annual reports of relevant organisations are used. Namibia is the second lowest densely populated country in the world with 2.533.794 inhabitants (United Nations Department of Economic and Social Affairs, 2017). Large parts of the country are uninhabitable due to land characteristics such as desert and mountains and large privately owned surfaces. Health, education and employment status are not stable and not in an alarming state but can all use large improvements. The economy is growing each year but is highly dependent on droughts, since there is a continuous scarcity of water in Namibia whereas the demand keeps increasing. Electricity supply is sufficient in urban areas but lacks in most rural areas. The same goes for ICT, which the government attempts to improve.

As for the transport infrastructure; Namibia has a relatively good and extended transport infrastructure. All four modalities - air transport, rail transport, sea transport and road transport - are present and used daily but the road infrastructure is by far the most advanced and most used. There are some attempts to improve the current transport situation in terms of safety, social and economic problems and sustainability. However, no reports on the actual outcomes of these attempts have been published yet and therefore it is hard to gauge if the projects improved the addressed issues. Besides, given past developments and future ambitions such as becoming the logistics hub of Southern Africa by 2022, the reality is that the road sector will keep on investing in roads in the near future. Therefore, this thesis only focuses on road infrastructure in Namibia.

V. Spatial data analysis

A multiple regression analysis is conducted to determine the relation between road density and quality and factors on which data is available on constituency level. These factors are education, health and employment. Road density and quality are not the only influencing variables for those factors, hence, if data was available, other predicting variables are also taken into account. This is indicated for each factor below.

For primary school, the number of schools per surface and the material of the walls of a household's house are used as predictive variables. The materials of the walls is a derivative of the welfare of the household. It is found that the road density influences the primary school enrolment together with the schools per surface and the materials of the walls. Not all three independent variables came out significant; road density remains insignificant. To avoid high insignificance and some reciprocal correlation, the schools per surface are taken out. It is logical that material of the walls predicts the education enrolment a lot more, since that is a derivative of income level. However, together with findings in literature, it can be concluded that the higher the road density, the higher the primary school enrolment. Hence, education enrolment can be improved through a higher road density.

As for the relation between road infrastructure and health; the under-five mortality rate (U5MR) is influenced by the access to safe water, apart from accessibility. The water access explains the U5MR for a large part, which is supported by literature. Water access mostly affects the U5MR through diseases such as diarrhoea. Hence, it is logical that this coefficient is large and significant. The road quality expressed in earth road ratio also explains the U5MR, from which it can be concluded that the quality of road infrastructure matters for (the accessibility of) health (care). The road density is not found to be significant in the multiple regression analysis, but with findings from literature and it correlating with U5MR by itself, road density is still used as a predictor for the U5MR, but just with a very small impact. Hence, a better road infrastructure slightly decreases the U5MR.

There are no other predicting variables for employment used than road density and quality. The quality of roads is the biggest predictor of unemployment rate. Road density comes out insignificant, but with confirmation from the literature study and the fact that singular regression between road density and unemployment does come out significant, road density can still be used as independent variable for the unemployment.

Lastly, of the reciprocal relations as shown in the framework, only the relation between health and education is confirmed by the data. The positive relation means that a better health usually goes hand in hand with a better education attendance rate and the other way around. Explanations behind the data The data shows largely discrepant performances of constituencies with similar road densities and therefore more detailed insights in the actual situation of constituencies in Namibia is desirable. This is done by choosing different constituencies with a similar, low road density of which three perform well and one that performs poorly on the factors. There is not one obvious reason for the discrepancy, although probably the main reason for a lot of constituencies having a low road density is the large uninhabited areas in the constituency. Another reason is that some of the (mostly northern) constituencies do not have many roads themselves but are close to other big towns so they still have quite good access to facilities. A third reason can be the shapefile containing mistakes. All in all, there is no easy way of accounting for discrepancy in performance of constituencies with similar road densities. These different explanations indicate that road density is not a comprehensive and strong indicator of road infrastructure. Unless used tactfully and logically, road density is not a meaningful way of measuring or assessing road network. An increase in road density could - in theory - imply constructing new roads anywhere within a constituency and performance on factors would go up (according to the data analysis). Therefore, one should bear in mind that, when using road density as a metric, attention has to be paid on where to construct roads and how much. Hence, if road density is used as a metric to assess road infrastructure, it should be used carefully and well-thought-out. To do so, future scenarios are identified in the next section that take this into account.

VI. SYSTEM DYNAMICS MODEL DEVELOPMENT

To test the effects of improved road infrastructure in future scenarios, a System Dynamics (SD) model is built. Figure 2 shows an overview of the Causal Loop Diagram (CLD) of this study, in which the relations between all variables are indicated. An important aspect of SD is including feedback structures, which are represented by feedback loops consisting of causal links from one variable connecting back to that same variable, after connecting to other variables (Sterman, 2000). Feedback loops often play a big role in the overall behaviour of the model which makes it important to identify them. The feedback loop in the framework of this study (figure 1) is represented by the bidirectional relation between road infrastructure and economic growth. The dashed line in the framework indicates the uncertainty of the relationship. Figure 2 shows the causal loop diagram of this study, with the uncertain relations indicated by dashed lines. A common way of dealing with uncertainties in SD is to explore the uncertainties, attempt to reduce the uncertainties as much as possible and to accept the irreducible uncertainties (Pruyt, 2013). Two models are developed; one without uncertainties and one with uncertainties. Both models include the following model components: road infrastructure, economic growth, education, health, employment, tourism, road safety and emissions. These variables are connected as shown in figure 2. The extended model includes the uncertain relations indicated as dashed lines between road infrastructure and economic growth by using sensitivity analysis varying the magnitude of the relationship between 0 and the maximum value. The models are verified with the mass balance test, which tests if the model output remains zero if road construction and upgrading is set to zero.

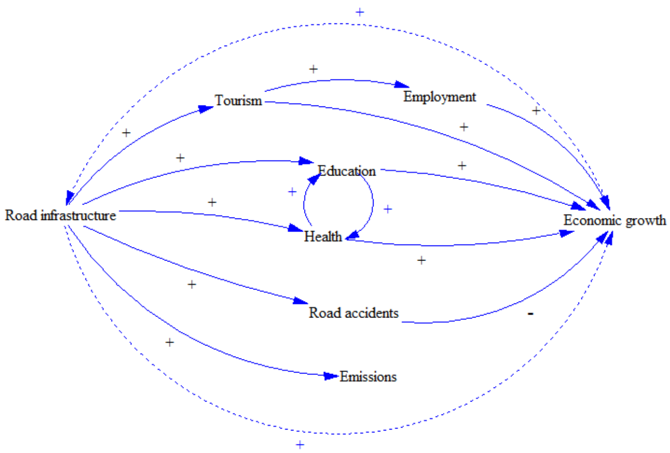

Fig. 2. Causal Loop Diagram

VII. FUTURE SCENARIOS

Two possible future scenarios with regards to road infrastructure in Namibia are identified: (i) the ambition of becoming the logistics hub of Southern Africa by 2022 and (ii) tourism enhancing. The model without the uncertainties is used to obtain the results as discussed below. The outcomes of the uncertainty model are briefly discussed after. The model is run from 2011 until 2022.

Results scenario 1 - Logistics hub 2022

Table I shows the improvements on road density, child mortality, unemployment and injuries due to the improvement of roads in the logistics hub scenario. The percentages indicate the change of each factor between 2011 and 2022. 0 means that there has been no change over time. The figures show the change from 2011 to 2022 of tourism and GDP on country level. The GDP is influenced by health, education, employment, tourism and road safety and therefore shows a different shape for instance the tourism graph by itself.

TABLE I. OUTPUT KPIS - SCENARIO 1

Constituency	Road density	Child mortality	Unemployment	Injuries
!Nami=Nus	+ 2,2%	- 5,1%	- 6,1%	0
Onyaanya	+ 15,7%	- 34,0%	- 3,5%	+ 2,7%
Musese	+ 9,1%	- 6,0%	- 8,2%	0
Linyanti	+ 4,4%	- 1,6%	- 7,1%	0
Mariental Urban	+ 3,1%	- 4,9%	- 8,1%	+ 3,8%
Sibinda	+ 7,1%	- 6,9%	- 6,5%	0

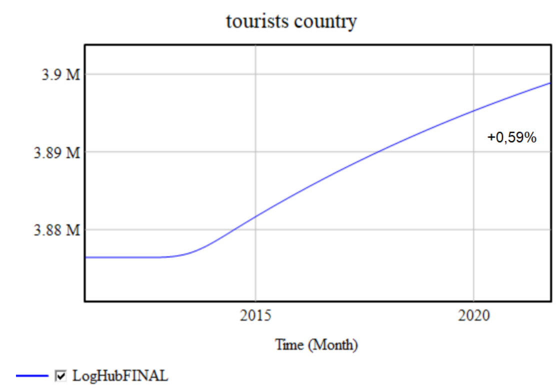

Fig. 3. Tourists increase - scenario 1

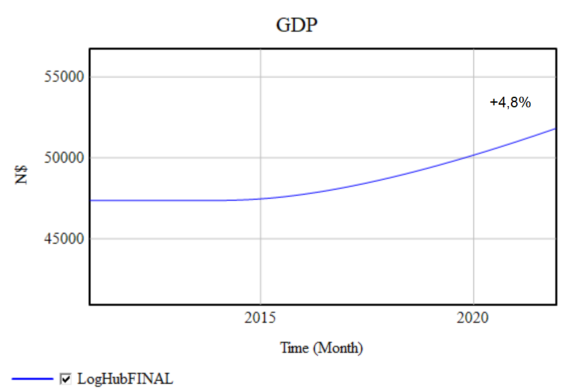

Fig. 4. Economic growth - scenario 1

Results scenario 2 - Tourism enhancing

Table I shows the improvements on road density, child mortality, unemployment and injuries due to the improvement of roads in the tourism enhancing scenario. The percentages indicate the change of each factor between 2011 and 2022. 0 means that there has been no change over time. The figures show the change from 2011 to 2022 of tourism and GDP on country level.

TABLE II. OUTPUT KPIS - SCENARIO 2

Constituency	Road density	Child mortality	Unemployment	Injuries
Arandis	0	- 6,6%	- 10,7%	+ 2,9%
Daures	+ 0,58%	- 3,0%	- 6,8%	0
Walvis Bay Rural	+ 0,90%	- 11,1%	- 9,4%	+ 7,4%
Daweb	0	- 2,0%	- 19,4%	0
Berseba	0	- 2,8%	- 4,8%	0
Karasburg West	0	- 5,7%	- 10,3%	+ 4,,%
Keetmanshoop Rural	0	- 1,3%	- 20,0%	0
Windhoek Rural	0	- 0,6%	- 1,5%	+ 4,5%
Khorixas	0	- 2,1%	- 6,4%	+ 2,3%

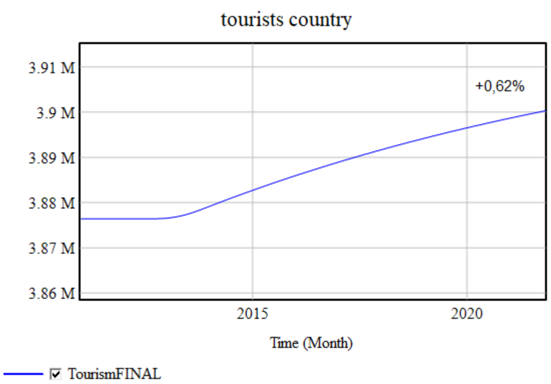

Fig. 5. Tourists increase - scenario 2

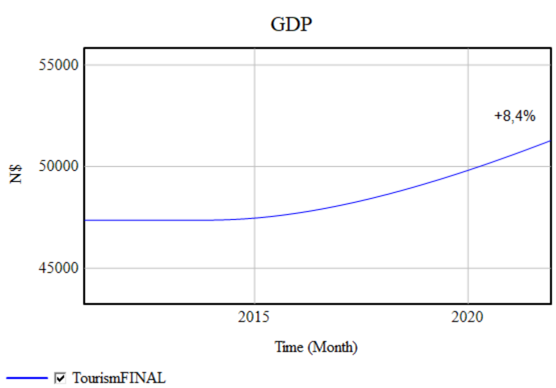

Fig. 6. Economic growth - scenario 2

Both scenarios improve health, tourism and employment. The primary school enrolment rates remained the same over time for both scenarios. Road safety increases for both scenarios due to upgrades to bitumen, but the extent to which it increases depends on the extra measures that are taken with regards to road safety. It can be increased more by campaigns or more controls. Emissions go up in both scenarios, because emissions are a direct result of constructing and upgrading roads. The tourism scenario attracts more tourists because the roads between the major attractions are upgraded to bitumen. Both scenarios are realistic and might happen in the future. The scenarios can and might be combined. Sensitivity analysis is conducted to assess the change of a parameter's behaviour when adding uncertainty to the model. For all parameters, the magnitude of the variables labelled as uncertainty (the effect of road infrastructure on economic growth and reversed) determines the extent of the growth. The structural behaviour does not change, but the parameters are quite sensitive to the addition of these uncertain relations. This makes sense, since the feedback loop is self-reinforcing; if for instance new roads are constructed, the economic growth will evidently increase, which increases building road infrastructure again.

VIII. CONCLUSIONS

In this study, a system dynamics model is developed which can be used to assess the effects of improvements in road infrastructure on the factors economic growth, road safety, emissions, education, health, employment and tourism. Besides, the relations between road infrastructure and the same factors are quantified for Namibia based on literature study and data-analysis. Lastly, two possible future scenarios for Namibia concerning road infrastructure are identified and used as input for the SD model, which showed the usefulness of the SD model and led to insights for the case of Namibia. These insights are discussed below.

Main insights Namibia

The main contributions and the insights for Namibia are (i) combining a large part of all available data from a large variety of sources; (ii) the identification of small but existing relations between road density and education, health and employment and between road quality and health and employment. It cannot be proven that tourism is road density or quality dependent. Looking at the number of tourists in each region, it appears that tourism is highly attraction based. It was found that most tourists highly value a good infrastructure and it is their number one remark on improvement for tourism in Namibia. Supported by literature and the framework, tourism would benefit from a better road network, and (iii) health, employment and tourism would benefit of the improvements of roads in both identified scenarios. Namibia is pursuing its ambition of becoming the logistics hub of Southern Africa by 2022. In this scenario, the roads belonging to the four corridors connecting Walvisbay Port to the hinterland on the concerning constituencies are upgraded to dual carriageway. The results are that health, employment and tourism would benefit of the improvements of these roads. Dependent on the effort on increasing road safety, this scenario could also decrease the number of road crashes and therefore injuries and fatalities. Injuries and fatalities are found to have a large impact on the GDP. The second scenario drawn for the Namibia case is that of enhancing tourism. The outcome of this scenario is that tourism would be increasing if the roads between the four major natural attractions are improved in terms of quality. Besides, both health and employment benefit from these upgrades; the U5MR and unemployment rate decrease in all constituencies the roads connecting the four attractions pass.

Limitations

The main limitation of this research is the limited availability or even a lack of data made this research difficult and this probably applies to most researches on developing countries. If more or better data would have been available, a different approach with better accessibility metrics could have been used. This research revolves around road density as a metric, which is - as established before - not a comprehensive and strong indicator for the road infrastructure in Namibia, mainly due to largely uninhabited areas without road infrastructure. This makes it difficult to draw conclusions and to predict effects of future scenarios. However, when being aware of the difficulty and complexity of road density as an indicator, conclusions are still useful. Predictions of the effects of a future scenario remain uncertain, but due to the extensive research that has been done on many facets, the insights gained in this study can still be considered useful and reliable.

A second limitation is the assumptions that are made regarding linear relationships between education, health and employment and road density. Assuming a linear relation between variables requires a high generalisation. Averages are taken of all constituencies to gain insights in the relation between two variables, which means that - in this research' case - different performances for similar road density smooth to one equal performance. By doing this, all constituencies are affected equally by more or better roads, where one would expect to have a bigger difference for constituencies with a current poor performance. Other shapes than linear relations were tested, but were not found to be significant with the used data. The biggest reason for this is probably the usage of road density as a metric. It became clear that this is not a very strong indicator, mostly due to large uninhabited areas which are counted in the road density metric. Ideally, better data would result in a more suitable and representative indicator of the road infrastructure, for instance the accessibility to different facilities in terms of time or distance. With this, the data analysis would probably be more accurate too and in this case, multiple regression analysis would give representative results. As for the data analysis done in this research, the identified relations do not serve as entirely valid and realistic relations, but they do indicate a relation which complies with literature. Therefore, it was still useful for the SD model, with the note that it should be considered to serve the purpose of facilitating *insights* in the dynamic system of road infrastructure and all factors and not a given and definite relation.

Further research

Four recommendations for further research have come forward: firstly, as this research proposed a method for developing countries, this method can be applied to many of these countries. Once more countries are researched, the outcomes could be compared or combined as well. For instance, for Namibia it would be interesting to know the effects of road infrastructure on the factors in neighbouring countries South Africa, Botswana, Zambia, Zimbabwe and Angola. The combination should include the logistics hub 2022 ambitions to see what the effects are on the whole region and if it has more benefits than becoming the hub.

Secondly, a lot of assumptions are made on different factors and variables due to the scope and time limitation. Each factor and relation between factors and road infrastructure could be investigated more and more extensively. For instance it is not taken into account if there is a difference in quality in health services (hospital, clinic, health service, etc.) or in the capacity of both health care facilities and education facilities. Another example is the fact that there was no data available on locations of jobs and other determining variables for employment.

Thirdly, the research only included correlations now which do not indicate direction. It is well-founded to assume causality based on literature study, but it would be better if causality could be investigated. This could be done by having data from different moments in time. For Namibia, this would be relatively simple since they have census data every 10 years. This implies that solely extra information over time on road infrastructure is needed. Hence, the road length and quality in Namibia should be recorded over time. Now it was only possible to find this road length and quality of one moment in time.

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