


SUSTAINABLE DESIGN OF TRANSPORT SYSTEMS

A TRANSPORT DESIGN STRATEGY IN RESPONSE TO THE GREAT
EAST JAPAN EARTHQUAKE CONSIDERING THE TRENDS OF
SHRINKING CITIES AND THE AGING SOCIETY

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Author

Robert Möhring

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Master of Science
Civil Engineering – Transport and Planning

Delft University of Technology

Graduation Committee

Prof. dr. ir. B. van Arem
Delft University of Technology, Department of Transport & Planning (chair)

Dr. ir. A. J. Pel
Delft University of Technology, Department of Transport & Planning

Dr. F. L. Hooimeijer
Delft University of Technology, Department of Urbanism

PREFACE

The work in your hands is the result of my graduation research for the Master of Science degree in the field of *Transport and Planning at Delft University of Technology*. It is the result of four years of passion and dedication towards sustainable transportation and the aim to design a future for ourselves and our generations to come.

This thesis is performed at the Delft University of Technology as part of the Delft Deltas, Infrastructures & Mobility Initiative (DIMI). Its aim is to work on integrated solutions for urgent societal issues with regard to vital infrastructural facilities for flood risk management and smart mobility. A work of what this thesis is contributing to in the field of smart mobility.

The aim of this research is to recommend designs for regional transport systems which is capable to adjust towards the trends of an aging society and its shrinking cities. In the end, the overall goal is to guarantee the mobility of all age and population groups, especially the elderly, and to support the regions thrive within an uncertain future due to economic, social and environmental shifts.

Result is a comprehensive study about balanced transportation including a new methodology to support backcasting in the field of transport design.

I am grateful to my supervisors Dr. ir A. Pel, Dr. F. L. Hooimeijer and Prof. dr. ir. B. van Aram for their support and discussions, but also for their critics and feedback along the way, when this thesis seemed to become a never-ending story.

Furthermore, I would like to thank my parents, and especially my mother, for their unconditional support and trust in the work I do.

But the most gratitude I give to A. S. A. Autar, who supported me with scientific advice, mental strength and an abundance of patience along the entire time of this thesis. Without you, this thesis would not be possible.

Robert Möhring
Den Haag, October 2018

ABSTRACT

This research focused on the sustainable design of a regional transport system, by considering the trends of the aging society and shrinking city into its design process. Most developed countries shrink and age, especially Japan, which has major impact towards transportation and land use. Applied is a backcasting approach, which includes these both trends and evaluates their impact along the transport dynamics within an adjusted 'land use and transport feedback loop'. The outcome shows that with regulative policies towards motorization and population densities a sustainable development can be initiated. Required is a change in the design of streets, public transportation and urban structures in order to maintain social integration, environmental protection and stable independent economy.

Key words:

Mobility, elderly, sustainable transportation, design, compact city, Japan, Miyagi

EXECUTIVE SUMMARY

Mobility is an essential precondition for the social participation of people and economic activities significantly depend on the design of traffic and transportation. However, in the light of demographic change, increasing urbanization and climate change, it is the challenge to guarantee the mobility needs of everyone and to design sustainable transport systems at the same time. In this context, innovative solutions obtain increasingly important.

To ensure that the various mobility needs are met in the best possible way while undesirable side effects are reduced to an acceptable level at the same time is the aim of sustainable transportation. Within its given framework of policies, a region or settlement of the future is one which is able to succeed in that aim and influences it in the long term.

The concept of sustainable transportation can therefore also be seen as a major contributor towards the development of compact cities, which in itself is basically in a conflict between spatial and environmental policy making.

Sustainable transportation and *compact cities* are two sides of the same coin. Both aim towards the mitigation of climate change and for a livable future of present and coming generations. The interaction of both cannot be denied. Moreover, it is widely understood, that transport system and spatial patterns are interrelated. However, the spatial and environmental impact of transport systems on areal (and further social) developments seems still underrated.

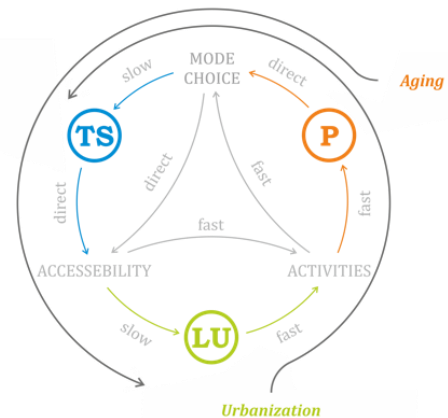
In short, spatial and transport interconnection can be described by the following feedback loop: (Wegener & Fürst, 1999; Rodrigue, et al., 2009)

- (P)** *The distribution of activities over the available space creates the need for people for travel and transportation.*
- (TS)** *Transportation is shaped by available technologies and result in different transport modes. As a result, these available modes shape the use of land and determine the growth of settlements as well as their environment and interconnection.*
- (LU)** *Settlements are formed by the provided capacities and requirements of available transport modes. Which in turn leads to the spatial distribution of activities. All of which, the combination of available transportation and distributed activities in space influences a person's decision on where to settle. It furthermore results in the demand for certain transportation and influences the societal integration.*

The relationship between transportation and land use patterns is not mutually exclusive as external factors, such as societal *trends*, also influence their development. (Chorus, 2012)

Of further interest are the trends the *aging society* and *shrinking cities* within developed countries. Both are external influencers directly impacting the physical and spatial structure of settlements and their transport system.

FIGURE 1 | DTL-CIRCLE



(source: own illustration and adaptation, based on Litman (2016) and Chorus (2012))

Question is *How to design a regional transport system, which enhances the mobility of the elderly and can support a regions thrive in the face of uncertain future economic, social, and environmental shifts?*

Key objective is to recommend certain designs for regional transport systems which shall be based on innovative solutions capable to face changing transport demands due to an aging society, flexible towards shrinking settlements and skilled to mitigate climate change.

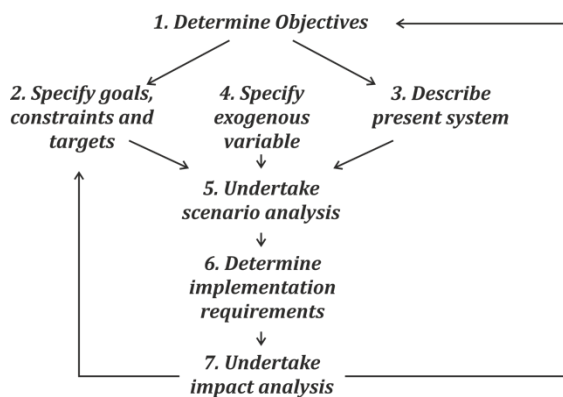
This main objective can be further divided into a theoretical and practical objective:

- *The **theoretical objective** of this thesis is to design a sustainable transport system to reassure the mobility of all people of all age groups, by including major trends, aside the goals for sustainable transportation, into the development methodology used for the design of a transport system.*
- *The **practical objective** of this thesis is to contribute to the improvement of the transport systems of the Miyagi prefecture, by analyzing the impact of the proposed design measures on social, economic, and environmental aspects.*

Case study within this thesis is the Miyagi prefecture. Which is related to the prefectures opportunity to reconstruct settlements and their transport systems under the concepts sustainability. As mobility is the key for societal interaction, also for people with high age, the rebuild of settlements and transport infrastructure shall create age-friendly urban environments and barrier-free transportation in order to provide transport possibilities which are less demanding on private motorization.

A potential method of *how* to adjust the given transport system towards shrinking settlements and an aging society is provided within this thesis. It uses the backcasting approach as described by Geurs & van Wee (2004) as fundamental outline (see Figure 2). The overall theory is the adjusted '*land use and transport feedback loop*' (see Figure 1) as first introduced by Wegener & Fürst (1999).

FIGURE 2 | OUTLINE – BACKCASTING



(source: Geurs & van Wee (2004))

Approach

The here presented methodology describes a desirable image of the future at first. In the given case study, that is a transport system, designed according to the goals of sustainability and able to guarantee the need of all age and population groups. It includes the trends of aging and shrinking and evaluates their impact along the transport dynamics within the DTL-cycle.

The transport system is the central point of view within this thesis. Focus is put on transport modes for passenger services operating on land in an urban and rural environment and their related infrastructural design measures.

People, and their behavior, is understood and included as travel behavior and transport demand which thus influences the transport system.

The thesis includes and follows the goals of sustainable transport planning as a key driver for the design of the proposed transport system.

Proposed measures are either focusing on infrastructure design changes (such as roadways, tracks and access and egress points) or service network design changes (lines and frequencies).

The study focuses on elementary as well as system related designs, such as street design (as element of a network) or network design (as network system).

Current Transport System

Related to distance and purpose, some transport modes are more suitable than others and a couple of possibilities exist to combine different modes with each other in order to combine their advantages. The usage of combined transport modes can therefore be seen as the result of an adequate application of them, assuming and requiring that nodes and hubs for transfers offer an efficient and present service.

However, the transport development in Miyagi shows an increased usage of private motorization over the last decades. Resulting in a rather automobile oriented transport system which further supported the regions urban sprawl.

External Factors

The trends of the *aging society* and *shrinking cities* have further consequences for transportation, land use and travel behavior. Accessibility and proximity for instance are crucial, in particular for elderly people, which are less willing to drive, do shorter trips and rely more on active modes.

Aging and shrinkage also occur parallel and are reinforcing each other. A sprawled city with a transport system based on private motorization is further reducing the elderly's mobility.

The solution against shrinkage and immobility of elderly is seen in a coordinated planning towards an adequate minimum population density within compact cities.

Which is also of major importance for the economic feasibility and stability of settlements. It is of need for social integration and connection, as well as of importance for basic social needs such as high-quality transportation. Density relates to the justification of transport services as well as the implementation of facilities for basic needs as well as certain housing typologies.

Having the DTL-cycle in mind, a change in housing typologies, also changes distances between activities and therefore human behavior. With a change in distances, certain transport modes are more suitable than others which in result impacts mode choice and transportation.

Scenarios

According to the Backcasting approach two kind of scenario can be distinguished. A *projective* and a *prospective* scenario. Both were performed in a qualitative approach. Temporal scope is the year 2045 with mid-point of the year 2035. Starting point in time is the available data from 2015. The time horizon is chosen to be long term in order to derive a sustainable transport system for decades and since changing on build environment within transport and land use usually is slow.

The *first scenario*, the **projective** scenario is set to extrapolate the current trends within the population, transport system and land use of Miyagi. Aim is to build a future image of the prefectures transport and land use for the year 2045. The construction of a projective scenario can also be named as **forecasting**.

The *second scenario* is the **prospective scenarios**. It is set to describe the transport system and land use patterns which fulfills the goals and targets of sustainable transportation and is built upon the before performed projective scenario. It highlights the discrepancies between both scenarios, with the aim to illustrates where large, disruptive changes have to take place in the current system. The construction of a prospective scenario can also be named as **backcasting**. (Geurs & van Wee, 2004)

The outcome of the *projective* scenario shows that the current trends of aging and shrinkage in an unguided development could lead to a further automobile dominant transport system which further incorporates urban sprawl and threatens the quality of a municipalities core as its economic and cultural heart.

The *prospective* scenario describes the desirable future transport system which is in accordance with the goals, objectives and targets of sustainable transportation. One mayor factor for attractive, efficient and balanced settlements is an adequate level of population density as well as a significant reduced degree of private motorization. The outcome shows that with regulative policies towards motorization and population density a sustainable development can be initiated.

The comparison of both scenarios' pointes out the following three aspects:

- a) *Automobile dominance does not include all transport participants.*
- b) *Private motorization leads to urban sprawl and both towards a high demand of resources.*
- c) *Zonal distribution and functional separation lead to high traffic and transportation needs as well as social segregation.*

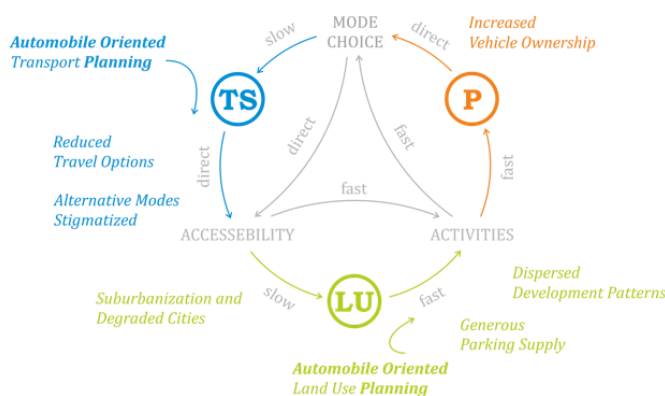
Multiple field-of-actions are identified in order to overcome the identified discrepancies. As a result, municipalities shall include these into a *smart shrinkage* and access-for-all development land use and transport development plan.

Major insight from the identified field-of-actions is the high importance of quality and coverage of the build transport infrastructure, defined and summarized by the objective group of **Universal Access (UA)**. **Efficiency (EF)** and **Safety (SA)** highly depend on the quality and coverage of a transport mode's infrastructure. The combination of the three objective groups – with *universal access* as foundation – makes environmentally friendly **Green Mobility (GM)** possible.

The identified field-of-actions are further related to the following three *design fields*:

1. **Street Design**, which is in favor for active modes and road based public transportation.
2. **Public Transportation Design**, which build up the back bone of an areas transport network and service.
3. **Compact City Design**, which promote adequate dense populations and housing types which support a distribution of different functions and short destination.

FIGURE 3 | AUTOMOBILE DEPENDENCY CIRCLE



(source: own illustration and adaptation, based on Litman (2002), Westphal (2008), Rodrigue, et al. (2009), Chorus (2012) and Victoria Transport Policy Institute (2016))

Concepts & Impacts

The comparison of both scenarios' lead to *four* development concepts, which are based on the identified field of actions and *eight* development principles of *Transit Oriented Development (TOD)*.

Many of the advised measurements are not new and generally known by decision makers and planners for decades. Nevertheless, their relevance is still given since most of them are not implemented yet.

Based on the amount of measurements it is concluded that sustainable transportation and compact cities are concepts which are based on the implementation of a number of individual measurements. One measurement on its own has low impact. But in combination their synergies unfold. Particular focus on service quality therefore shall be set towards transport hubs or access points, where people enter, egress and transfer between.

In relation to the identified design-fields the following design concepts and impacts are identified:

1) Street Design

... aims to balance different type of user and modal expectations that various groups place on the scarce resource of '*public space*'.

Major target in the prospected transport system is the reduction of private motorization and increase of walking and cycling as the major mode to choose. In order to do so, a strong and sufficient walk and cycle network must be implemented. In the end of the DTL-cycle, street design shapes traffic and transportation.

Universal Access (UA) is achieved by an intuitive, self-explanatory and attractive street design, which gives more space towards active modes and road based public transportation. Their integration is increased due to a clear hierarchical structure and homogeneous design.

Street design impacts *Efficiency (EF)*. Services are more reliable, punctual and faster due to modal separation. Furthermore, energy cost reduces due to smoother driving. Operational cost and the need of investments decline, because of lower traffic volumes. Sustainable street design accommodates all user groups, due to barrier free construction. *Safety (SA)* increases due to lower vehicle speeds, reduced traffic volumes and adequate space for active modes.

All of which aids towards *Green Mobility (GM)*. Emissions, traffic noise and water pollution decline.

2) Public Transportation Design

... aims to provide a high-quality service, which directly relates to network design, infrastructural separation and priority in traffic.

Within Miyagi, the given railways system can be developed further into the backbone of the prefectures transportation. Required is a more *frequently* served network, fed and supported by a

dense network of prefectural bus services which operate on their own guideways. Service quality, appearance and coverage of public transportation influence the modal acceptance.

Universal Access (UA) is achieved by providing mobility stations which combine individual modes (walking, cycling, car- and bike-sharing) with collective modes (railways and busses).

More frequent services, punctuality and higher travel speed increase the performance of public transportation and so its *Efficiency (EF)*.

Energy cost decline due to collective transportation, as well as operational costs. *Safety (SA)* increases due to separate infrastructure, active stations and traveling in groups.

Traveling in groups supports *Green Mobility (GM)*. Emissions, traffic noise and water pollution declines. Shifting to modes of public transportation can mitigate the effects of climate change.

3) Compact City Design

... aims for the balance of different functions and activities that various groups place on the scarce resource of available space. This directly relates to transport infrastructure and housing typologies.

Furthermore, bus stops and train stations will become *a) mobility hubs* which provide easy and guaranteed connections towards many other modes as well as *b) central squares* of basic services for daily use and social interaction.

Shrinkage will be coordinated towards stops and stations of collective transport modes. All in order to provide *concentrated* and *fragmented* compact settlements which provide minimum population densities and mixed functionality. The compact design of settlement directly influences mode choice.

Universal Access (UA) to active modes and public transportation is increased due to a dense and functionally mixed development around bus stops and train stations.

The *efficient (EF)* operation of urban infrastructure increases cost efficiency, since a reduced transport network and denser urban structure demand less maintenance and investments, which lowers operational costs and fuel consumption per capita. Walking as a primary mode of choice increases public health. In return, crashes, traffic casualties and assaults are minimized. The compact city is *safer (SA)*, due to a reduced exposure to traffic and the social over watch.

Spatial density and a functional mix of activities directly impacts *Green Mobility (GM)*. One effect is the positive impact on mode choice which shifts towards active modes, reduces traffic and its related exposure to emissions and pollutants. A coordinated

Conclusion & Recommendation

The backcasting approach provides a general frame for any research in the field of transportation. In combination with the DTL-circle, this approach is capable to directly evaluate the impact of a measurement towards land use, demand and transportation. Backcasting in combination with the DTL-circle therefor is a sufficient tool for any other case study in the world.

Mobility for everyone – not just the elderly – is not a question related to transport technology – It is a question to spatial arrangement, design quality and the linkage of available modes.

It is not *just* a matter of transport engineering or related to the prospects of automated driving. Mobility is the result of modern skills of structuring space and the distribution of activities with the aim to bundle transport demands. Both with the aim to maximize urban and transport quality by minimizing energy consumption per capita.

Special requirements for improvement are seen in the functionality and appearance of streets and transport hubs and their degree in comfortable transfers.

With this in mind: A synergy between transport and urban planning which aims for a reduction in car dependency will *automatically* lead to a natural development of active and car independent elderly in a compact urban environment.

'*Compact cities*' is a concept for urban the environment which should stronger be included in traffic and transport planning. At the same time urban planning can include the knowledge about modal system characteristic of given (and potential) transport modes in order to provide better designs and concepts.

Each step of the here presented thesis has the power to become a research on its own. Either in a general or specific context.

In this context, the following recommendations are summarized for further research:

1. *Minimum Population Densities for feasible Public Transportation in relation to the degree of motorization*

Settlements with a medium rise and coverage housing typology show that inhabitants are more likely to walk, cycle and use public transportation.

It is of interest, how the reduced degree in private motorization within a regions modal split is affecting the required minimum population density of settlements, which is found to justify collective modes.

2. *Shrinking development concepts in the Japanese context as guidance for the compact city development*

Contraction, fragmentation, perforation and dispersion are the four concepts of shrinking cities which were elaborated for the east German context.

It is of interest to further investigate, how these four development concepts are applicable to the shrinking areas of Japan.

3. *Sustainable street design in Japanese context as measurement to increase road safety and walkability*

The Netherlands pioneers in traffic and road safety. This is strongly related to the Dutch street design guidelines which aim to balance the needs of all traffic and transport participant and lead to the design concepts of '*sustainable roads*'.

It is of interest, how the Dutch street design principles could be brought into the Japanese context. Especially the concepts of sustainable roads and road hierarchy should be investigated for Japan.

4. *Design guidelines for the interaction and combination of collective and non-motorized transport modes*

With the aim to strengthen multi-modal trips, it is of importance on how to design sufficient infrastructural networks and transfer hubs for collective and active modes.

It is therefore of interest, to further investigate the user experience of transfers with the aim to better it. It is expected that, the quality of stay around points of transfers positively impact the experience to transfer.

New concepts, such as shops, institutions or just public bookshelves which are integrated in bus stops could strengthen collective transportation and increases the acceptance to transfers. However, sufficient public transportation offers frequencies, which result in short waiting times.

Content

Part One, the Introductory, states the purpose and the goals of this thesis. Introduced are transport dynamics and how they are influenced by aging, shrinkage and climate change. Furthermore, the methodology of backcasting is added as structural foundation of this research and methodology of this research.

Part Two, Objectives, Goals and Targets, defines sustainability for transport services and infrastructures for the mobility of today's and future generation. Aim is to guarantee universal accessibility, safety and efficiency, while minimizing carbon emissions and other environmental impacts.

Part Three, the Current System and External Factors, presents the current established transport system of the case study, the Miyagi Prefecture. Furthermore, it discusses major trends as external factors which are shaping the region's demographics, transport system and land use.

Part Four, Exploring the Future, merges the identified transport dynamics, goals of sustainable transportation, current system of the Miyagi Prefecture and its influencing external factors in order to describe the forecasted and backcasted potential transport system. Potential concepts and designs are derived from the gained insights.

Part Five, Generalization, Discussion, Conclusion and Recommendation evaluates the gained insights, elaborated scenarios and potential transport designs.

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PART ONE

INTRODUCTION

Mobility, traffic and transportation are of essential importance for economies and societies. Mobility is not just an essential precondition for the **social** participation of people or **economic** activities. Its performance and integration also significantly depend on the design of traffic and transportation systems.

In addition, the field of traffic and transportation got exceptional attention, in particular as a result of growing efforts in **climate protection** and the reduced consumption of fossil energy within recent years. Faced with an increasing need for action, regions and settlements are challenged to redesign their traffic and transportation system in such a way, that CO₂ emissions and fossil energy consumptions are reduced in a significant amount.

Need for action arises mainly from the containment of unwanted side effects of motorized forms of transportation. In addition to CO₂ emissions, private motorization in particular is linked to a high spatial demand, noise and emissions as well as traffic accidents. It also impairs traffic safety and the freedom of pedestrians and cyclist to move.

To ensure that the various mobility needs are met in the best possible way while undesirable side effects are reduced to an acceptable level at the same time is the aim of **sustainable transportation**.

The fundamental goal of *sustainable transportation* is to “balance between social, economic and environmental aspects of transportation with purpose to maintain our current generations need on transportation but without causing great or irreparable harm to future generations throughout the world” (Litman, 2016).

Within its given framework of policies, a region or settlement of the future is one which is able to succeed in that aim and influences it in the long term.

In addition, the **compact city** policy is a spatial concept in the field of urbanism, meant to strengthen the city as a place which combines livability and workability. To do so, it faces the urbanization of open space and the increase of mobility. The concept contributes to spatial quality of urban areas and country sides. It also has a positive effect on the environmental quality, partly because of an expected reduction of travel distances. Urbanization and mobility are today more than ever issues to be dealt with. The compact city therefore is a functional and social place where daily needs are in walkable distance. (de Roo, 1998)

The concept of sustainable transportation can therefore be seen as a **major part** of and contributor towards the development of compact cities, which in itself is basically in a conflict between spatial and environmental policy making.

In the end, *sustainable transportation* and *compact cities* are two concepts which aim towards the mitigation of climate change and for a livable future for coming generations. The interaction of both cannot be denied. Moreover, it is widely understood, that transport system and spatial patterns are interrelated. However, the spatial and environmental impact of transport systems on areal (and further social) developments seems still underrated. (Wegener & Fürst, 1999; Rodrigue, et al., 2009)

Spatial and transport interconnection can be described as follows:

- a) *The distribution of activities over the available space creates the need for people for travel and transportation.*
- b) *Transportation is shaped by available technologies and result in different transport modes. As a result, these available modes shape the use of land and determine the growth of settlements as well as their environment and interconnection.*
- c) *Settlements are formed by the provided capacities and requirements of available transport modes. Which in turn leads to the spatial distribution of activities. All of which, the combination of available transportation and distributed activities in space influences a person's decision on where to settle. It furthermore results in the demand for certain transportation and influences the societal integration.*

The relationship between transportation and land use patterns is not mutually exclusive as external factors, such as societal **trends**, also influence their development (Chorus, 2012).

In order to design and provide transport systems which ‘maintain our current generations needs without causing great or irreparable harm to our future generations worldwide’, the discussion of sustainable transportation must take place with an understanding of the larger trends of societal and technological development as these ‘external factors’ impact mobility and personal preferences.

According to the *Mobilizing Sustainable Transport for Development* report of the United Nations will mobility be shaped by the following five trends within the upcoming decades: (United Nations, 2016; SuM4All, 2017)

1. *Demographic changes*
2. *Urbanization and urban-rural integration*
3. *Global supply chains and trade routes*
4. *Digital connectivity*
5. *Development of greener, more efficient propulsion technology.*

The intention here is to have a closer look into the first two identified trends, *Urbanization* and *Demographic Changes*, as both of them directly impact the physical and spatial structure of settlements and their transport system. It is therefore to consider these trends into the development process of sustainable transport systems and compact cities.

First trend of interest is the **Demographic Change**. The *Mobilizing Sustainable Transport for Development* report states, that mainly in *developed countries* the population is aging and shrinking, while mainly *developing countries* face a rapid growth and a young population. (United Nations, 2016)

Both developments have consequences for transportation, land use and travel behavior. Accessibility and proximity for instance are crucial, in particular for the elderly. However, younger generations seem to be driven by newly emerging trends such as the “*sharing economy*” which is depending on smart phone connectivity and therefore ‘*digital connectivity*’. These trends however, vary between regions and the regions level of development. Requesting that all policy decisions must take account of the specific regional context.

The second trend considered is **Urbanization**. The United Nations expect, that by 2050, “*the world’s urban population have grown by 2.5 billion people, reaching 66% of the total global population. Africa and Asia together will make up nearly 90% of this increase until 2050 [...]*.” (United Nations, 2016)

Of importance is that in some *developed countries* urban centers have diminishing populations and pockets of very low density. Following a further global context, some *developing regions*, still have their majority of the population residing in rural areas. “*In both developing and developed countries, rural connectivity is an ongoing challenge, especially as economic and social activities and opportunities are often based in cities, towns and markets.*” (United Nations, 2016)

Settlements in *developed* and *developing countries* alike face the same *effects* in transportation: Congestion, pollution, energy consumption, traffic safety and spatial demand. The transport landscape in urban agglomerations is often highly inequitable and automobile-oriented. Mostly poor and disabled people are left with inadequate means to access the economic and social centers of the cities. When unguided, those developments hold a threat towards livability of a location, due to the loss of space for people to interact. Another aspect to keep in mind is the burden of climate change, which “*adds another layer of urgency and complexity to the problems decision makers must address in their quest to create sustainable cities.*” (United Nations, 2016)

General *aim* shall therefore be to create sustainable settlements with an equitable transport system accessible for all which will enable less reliance on private motorization and therefore reduces their negative side-effects on people and the environment. (United Nations, 2016)

As shortly mentioned before, in most developed countries the population is *shrinking* and *aging*, while in developing states, population is growing rapidly and getting younger. One example is Germany with a median age of 46.5 year in 2015. India on the other hand had a median of 27.3 years. Many German cities, especially in the eastern part (former GDR) have experienced significant population declines after the country’s reunification, posing the opposite transport challenges to those experienced in Indian cities where the population is growing every year. (United Nations, 2016)

Japan is recognized as the fastest aging country of the world. The *Statistics Bureau of the Ministry of Internal Affairs and Communications (MIC)* which represents the official statistical agency of Japan, estimated a nationwide decrease in population from 127.0 million in 2015 to 98.2 Million until 2050 (-22.7%), assuming a low fertility rate. At the same time the amount of inhabitant at age 65 and over increase from 33.868 million in 2015 (26.6%) to 38.406 million in 2050 (39.1%) (MIC, 2017a).

A development what will also affect cities to shrink. A few years earlier, in late February 2011, The *National Land Council of Japan’s Ministry of Land, Infrastructure, Transport and Tourism (MLIT)* announced, that about 20% of the current inhabited land will be completely depopulated by 2050. Additional 20% of land will have fewer than 10 residents per km². Both assuming that the given demographic trends will continue. As consequence, 40% of the currently inhabited areas of Japan will be virtually uninhabited by the mid of the 21st century. Those estimations were announced one-month prior to the *Great East Japan Earthquake* which took place on March 11th 2011. (Ichinose, 2012).

The tsunami devastated an area of Japan which had to face an aging society and shrinking cities already for years. However, the *MIC* estimated that the population of Miyagi will decrease further. From 2,339,899 in 2015 to 2,046,219 in 2035. By 2045 the population could shrink to 1,809,021.

The estimated decrease in population is taking place in all municipalities while the countryside population is declining faster compared to the capital and economic center called Sendai. Most of the by the tsunami affected municipalities wanted to “*restore everything just as it was before, and as soon as possible*”. But it was, and still is, questioned how a reconstruction of the lost would be sustainable facing a further depopulation and aging. (Ichinose, 2012; eCitizen, 2018)

In this context, Ichinose (2012) concluded that the design of reconstruction plans should use a *backcasting* approach that predicts future population and aging trends in order to build cities and regions that are sustainable for decades. A conclusion which inspired the author to perform this research.

THEORETICAL FRAME

The **theoretical frame** within this thesis combines the theories of Wegener & Fürst (1999), Rodrigue, et al., (2009) as well as Chorus (2012).

The spatial distribution of activities requires trips to overcome the distances between them. This can either be in the form of new infrastructure or a more efficient operation of existent facilities. This increases areal accessibility and determines the location of activities. The interaction of spatial development and transportation was introduced by Wegener & Fürst as the 'land use transport feedback cycle' in 1999.

Rodrigue, et al. (2009, p. 233) elaborated that the spatial location of activities and specific land use patterns are influenced by the urban form and spatial structure. He describes the urban form as "the spatial imprint of an urban transport system as well as the adjacent physical infrastructure." The spatial structure is the "set of relationships [which] arise out of the urban form and its underlying interaction of people, freight and information."

Chorus (2012) elaborated on the complex development dynamics within Wegeners feedback cycle. He pointed out that activity patterns "can adapt relative fast [to improved accessibility], while it takes much longer for a transport and land use system to adjust".

The combination of the three authors insights lead to the in Figure 0-1 illustrated feedback circle.

The integration of the three resulted in a model similar to Wegeners 'land use transport feedback cycle'. The human factors (as in peoples' demand for transport) is pointed out stronger. The model also includes development dynamics which are taking place within the feedback cycle as pointed out by Chorus (2012). In addition to the aforementioned adaptation towards increased accessibility, mode choice directly relates towards the degree of accessibility, while it takes much longer for a transport system to adjust towards a change in demand.

Within this thesis, the here, by the author derived model will be referred to as the *Demand, Transport and Land use feedback circle*, or in short *DTL-cycle* (Figure 0-1). Its sections are *People / human factor (P)*, *Transport System (TS)* and *Land Use (LU)*. The model in short works as follows: Human activities are mainly influenced by the spatial distribution and location of *activities*. Peoples intention to carry out or reach an activity influences their *Mode Choice* behavior. Mode Choice derives the capacities and requirements of the given Transport Systems, which as a result allows a mode related *accessibility* of the given Area. Land Use and its development derives into the distribution of activities.

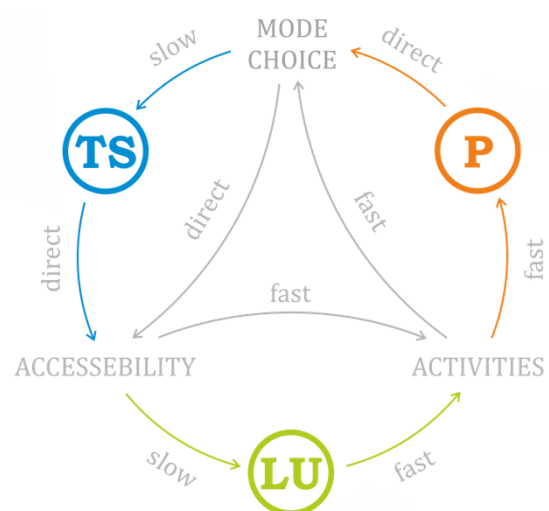
Those three sections and the underlying mechanisms are further used as foundation within this thesis to explore, define and distinguish development patterns for the sustainable transport development.

However, the feedback circle between *people*, *transport system* and *land use* patterns are not mutually exclusive. External factors influence the segments development and as a result the development of a transport systems and the use of available land. (Chorus, 2012)

- **Land use (LU)** developments are not only influences by accessibility, but also by external factors such as the availability of developable land, local land use policies, regional demand for new developments and the appropriateness of adjacent land use.
- Activities are not only determined by land use patterns. Attitudinal, socio-economic characteristics and lifestyle have a strong influence on **travel behavior (P)**.
- The development of **transport systems (TS)** and their respective networks are not only determined by travel demand, but also by developments that influence transport supply, such as infrastructure invesments, technological innovations or transport policies.

The following sub-chapters therefore will further elaborate on the three DTL-sections and their mechanisms.

FIGURE 0-1 | DEMAND, TRANSPORT AND LAND USE FEEDBACK CIRCLE (DTL-CYCLE)



(source: own illustration, based and adapted from Wegener & Fürst, 1999 and Chorus, 2012)

PEOPLE

Commuters, Travelers or Users – the demands and resulting mode choices of *people*, either as a single person or collective group, are the starting point of the DTL-cycle.

The segment, indicated by a 'P' describes not just the start but also the end of the DTL feedback loop. Human activities, under influence of *travel distance, times* and *costs* do effect *trip decision* and *destination choice*. All of which leads to the *transport mode of choice*, which is used to reach the location of activity.

The location of activities determines the location of human activities. The spatial distribution of activities requires trips to overcome the distances between them. Within this thesis, activities are seen as actions or realized preferences of people. 'Going to work' is seen as a human activity, while 'work' itself is seen as the location of activity.

However, a personal *attitude, socio-economic characteristics* and *lifestyle* play a far stronger role by influence travel behavior. For instance, people with higher income are more likely to own and use a car than people with a lower income or elderly. It is for this reason, why the last two groups tend towards public transportation in order to be mobile. Nevertheless, density in settlements positively influence mode choice towards collective and active modes throw-out all social classes, above-all educated people. (Chorus, 2012)

TRANSPORT SYSTEM

Each transport mode is supported by a set of functional elements which define an infrastructure with network and result in modal capacities and service qualities. Based on the Mode Choice a related *route choice* (through the network) and *link loads* (related to the systems capacities) are deriving. Route choice and link loads result in *travel times, distances and costs*. The design of the network, vehicles speeds and system capacities eventually define the *accessibility* of a location.

The development of transport systems and their respective networks are not only determined by travel demand, but also by developments that influence transport supply, such as *infrastructure investments, technological innovations* or *transport policies*.

Perhaps most significant impact of a transport system on land use are its impact on property values. Properties near railway stations or stops of high-quality public transport services have higher property values compared to similar properties located further away of such. (Chorus, 2012)

An '*backwards*' impact of a transport system on demand is seen in infrastructure quality. Qualitative high infrastructure also offers a high-quality of service which in turn attracts users and influences their mode choice.

LAND USE

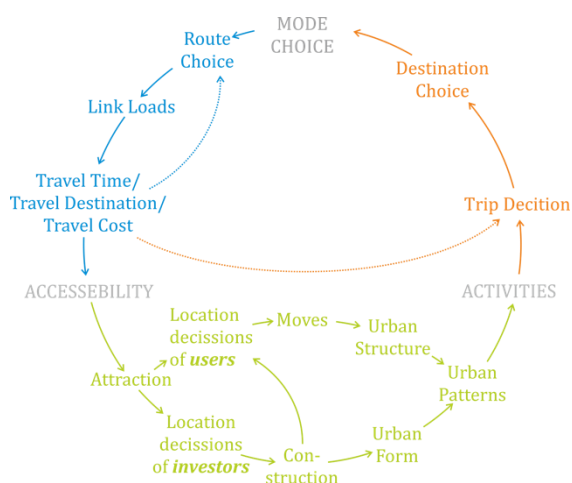
An increase in *accessibility*, resulting from transport improvements, co-determines the location decision of landlords, investors, households and firms. The spatial imprint of transport infrastructure and the build adjacent infrastructure changes and defines the urban form in the long run.

The resulting interaction of people defines the settlements spatial structure. Both resulting in the spatial distribution of activities, the urban patterns which determines human *activities* and their demand do overcome space.

Land use developments are not only influencing by accessibility. But also, by *availability of developable land, local land use policies, regional demand for new developments* and the *appropriateness of adjacent land use*.

Most significant impact of Land Use on Demand can be seen in neighborhoods which are characterized by a *high density, mix of land use* (functional diversity) and *pedestrian oriented street design*. Neighborhoods developed along these three principles indicate a change in Mode Choice towards more active modes (walking and cycling) and Public Transportation.

FIGURE 0-2 | DTL-CIRCLE – INTERNAL MECHANISM



(source: own illustration, based and adapted from Wegener & Fürst, 1999; Rodrigue, et al., 2009 and Chorus, 2012)

METHODOLOGICAL FRAME

The **methodological frame** of this thesis uses the outline of the general *backcasting approach* elaborated by Geurs & van Wee (2004, p. 51). Backcasting is based on the underlying question on *what actions must be undertaken in order to reach a certain goal*. Purpose and direction of development are derived by the goals of sustainable transport systems as derived by Litman (2016, p. 6) and the United Nations (2016).

Within this chapter, the concept of *Sustainable Transportation* is introduced first in order to describe developments aim of transportation. A further more detailed elaboration on it is provided in Chapter 2 (p. 13). Further, the backcasting approach is discuss which allows to describe a desirable future transport system able to provide mobility for all in accordance to the goals of sustainability.

SUSTAINABILITY FOR TRANSPORT PLANNING

The starting point for any good discussion, meeting, or workshop on sustainable transport system development should be a shared understanding of what sustainable transport system development actually is. The sustainable development of transport systems should be understood by planers, politicians, engineers and users alike and facilitate description and discussion. The challenge is, that the concept of sustainable transportation must be simple, relevant and intuitively understandable, while not over-simplifying the complexity of how transport systems function. (de Roo, 1998; BAU, 2017)

Sustainable Transportation aims to find a *“balance between social, economic and environmental aspects”*. The goals itself are summarized by Litman (2016, p. 6) presented in Table 0-1. Each goal fits into its own aspect of sustainable transportation, even though they often overlap. The prevention of air, noise and water pollution for example is considered an *environmental* matter, but it affects human health (*social*) as well as the fishing and tourism industries (*economic*). (Litman, 2016)

Similar to Litman (2016) the *High-Level Advisory Group on Sustainable Transport* of the United Nations defined sustainable transportation as *“the provision of services and infrastructure for the mobility of people and goods – advancing economic and social development to benefit today’s and future generations – in a manner that is safe, affordable, accessible, efficient, and resilient, while minimizing carbon and other emissions and environmental impacts.”* (United Nations, 2016, p. 10)

Within this thesis the goals of sustainable transportation (see Chapter 2 and Appendix 01) are the foundation and overall aim which the design of a transport system shall follow.

TABLE 0-1 | SUSTAINABLE TRANSPORTATION GOALS

<i>Economic</i>	<i>Social</i>	<i>Environmental</i>
<i>Economic productivity</i>	<i>Equity / Fairness</i>	<i>Climate change prevention and mitigation</i>
<i>Local economic development</i>	<i>Safety and security</i>	<i>Air, noise and water pollution prevention</i>
<i>Resource efficiency</i>	<i>Community development</i>	<i>Non-Renewable Resource Conservation</i>
<i>Affordability</i>	<i>Cultural heritage preservation</i>	<i>Open space preservation</i>
<i>Operational efficiency</i>	<i>Public fitness and health</i>	<i>Biodiversity protection</i>
<i>Good Governance and Planning</i>		
<i>Integrated, comprehensive and inclusive planning</i>		
<i>Efficient pricing</i>		

(source: own illustration based on Litman, 2016)

BACKCASTING FOR SUSTAINABLE TRANSPORT PLANNING

Backcasting as a term was defined by John B. Robinson in 1982 as “*working backwards’ from a particular future end-point to the present to determine what policy measures would be required to reach that future*” (Robinson, 1982). Its underlying question is *what actions must be undertaken in order to reach a certain goal.* (Geurs & van Wee, 2004)

This is in contrast to forecasting, where the development of a transport system is based on projecting a potential future, based on socio-economic data and developments. (Geurs & van Wee, 2004)

Forecasting scenarios are a common tool in transport planning. These studies assess transport problems due to current and future transport activities which are based on socio-economic trends. According to Geurs & van Wee (2004) “*forecasting [...] seems to rely fully on casual determination, i.e. mathematical models are built with the intention of forecasting the future development of a system given a set of initial conditions*”.

Transport demand models forecast future travel demands based on socio-economic developments. Backcasting studies on the other hand are less common yet and “*should [...] be judged in the context of discovery, [as] a creative process to get ideas, rather than the scientific justification*” (Geurs & van Wee, 2004). Backcasting offers more space for intentional explanations of desires and beliefs how a system should develop. (Geurs & van Wee, 2004)

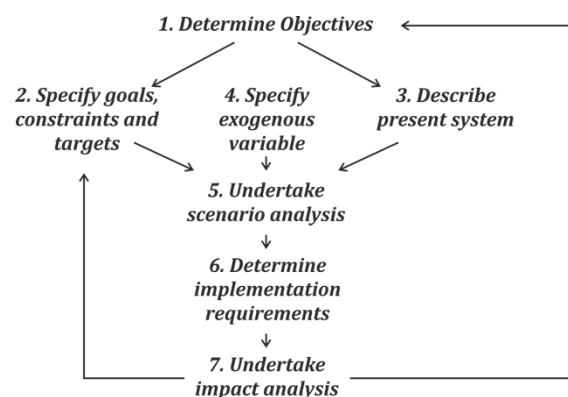
While Forecasting is *projecting* a future, based on extrapolation of current socio-economic trends, Backcasting is *prospecting* a future and therefore able to highlight discrepancies as well as potential milestones to reach between the current and desirable future state and can incorporate large and even disruptive changes. (Geurs & van Wee, 2004)

Geurs & van Wee (2004) pointed out that no ‘*standard recipe*’ is given for developing scenarios, since scenario development may involve several analytic and research methods.

A general outline of backcasting, adapted by Geurs & van Wee (2004), is as follows (also see Figure 0-3):

- **Step 1. Determine the objectives.**
Describe the purpose of the analysis, lay out temporal, spatial and substantive scope and decide on the number and type of scenarios
- **Step 2. Specify concrete goals and targets**
...based on the objectives outlined in step 1, where possible qualitative goals shall be expressed in quantitative targets to provide measurable points of reference to the scenario analysis.
- **Step 3. Describe the present system**
(demographics, transportation system, etc.) and determine the driving forces of change.
- **Step 4. Specify external variables**
... such as perditions on economic growth, demography, stability of the supply of fossil fuels and international relations.
- **Step 5. Generate future scenarios**
Carries out the scenario analysis.
- **Step 6. Determine the implementation**
requirements or the behavioral, institutional, and policy responses that are required at different spatial levels to influence the driving forces and achieve the future scenarios. If possible, time paths should be established for the different implementation measures to reflect an incremental and sequential approach.
- **Step 7. Conduct an impact analysis**
that consolidates scenario results; analyzes social, economic, and environmental impacts; and compares the analysis results with the goals and targets established in Step 2. Iterations (Steps 2, 4, and 5) should be conducted if necessary to ensure consistency between goals and results.

FIGURE 0-3 | OUTLINE – BACKCASTING



(source: Geurs & van Wee, 2004)

CURRENT SITUATION

A **transport system** is understood as “a set of functionally linked components, which are delimited according to a certain feature from the totality of all system elements present in the transport sector. The delimitation takes place, for example, according to spatial, temporal, technical, organizational, political, legal or operational aspects and serves to simplify the handling of complex traffic structures. There are open or closed traffic systems. The isolated consideration of a traffic system neglecting the system environment can lead to erroneous conclusions.” (Ammoser & Hoppe, 2006, pp. 37-38)

A “transport system embodies the interaction of transport modes for overcoming space of people, goods and messages, with system components linked together by functional interrelationships to create a complex structure of different traffic and transport sectors and markets on which transport companies can operate with three action parameters: variation of price, quantity and quality of services.” (Ammoser & Hoppe, 2006, pp. 37-38)

Design is a “plan or drawing produced to show the look and function or workings of a building, garment, or other object before it is made” (Oxford dictionaries, 2018). Designers, consider the end user of their designed object and think about functionality, usability and user friendliness. (Colville-Andersen, 2012)

As a conclusion, **Transport System Design** therefore shall plan and show the look of functionally linked components of the transport sector. It shall plan and show the interaction of transport modes and therefore consider their functionality, usability and user friendliness. Furthermore, a **sustainable transport system design** aims for the balance of economic, social and environmental aspects in order to maintain our current mobility needs without harming the needs of generations to come.

Case study

Within this thesis, the Miyagi prefecture is chosen as case study, which is related to the unique combination of circumstances of this area. The region is shrinking and aging since years and the reconstruction process holds the opportunity to rebuild a transport system and the settlements under the principles of sustainability and compactness.

Figure 0-4 illustrates the Tōhoku region in Japans prefectural context and highlights the location of the Miyagi prefecture. The figure also indicates cities, towns and villages as well as their spatial occupation.

It is for this reason why the two trends, **Demographic Change** and **Urbanization**, are seen in context of the developed country of Japan and are therefore reduced towards the trends of the *aging of society* and the *shrinkage of cities*.

As mobility is key for societal interaction – *also for people with high age* – the reconstruction process shall consider the currently occurring trends of shrinkage and aging in order to create age-friendly urban environments and barrier-free transportation.

Mayor geographic characteristic of the Miyagi prefecture is its location in the north-eastern part of Japans main island *Honshu* and its direct access to the Pacific Ocean. It covers an area of 7,282 km² which makes about 3.6% of whole Japan. (eCitizen, 2018)

By the Japanese census of 2015, about 2,33 Million people live in Miyagi, which are 1.5% of Japans total population. Nearly half of Miyagi’s population, 1,08 Million, live in the municipality and prefectural capital of Sendai. Miyagi’s population density of 320.5 Inh/km² is slightly under the Japanese average of 336.3 Inh/km² but makes it the densest populated area of the Tōhoku region. Miyagi ranks 14 out of 47 prefectures when it comes to inhabitants. (eCitizen, 2018)

Current situation

At the current state, no suitable method combines external factors, such as the identified trends, with the goals of sustainability.

Furthermore, the aim of decision makers and planners alike usually see transportation and urban design as two, more or less, separate disciplines. The interaction of both is not fairly considered in the design process of both.

Evaluated situation

As Ichinose (2012) concluded, decision makers and planners within the Tōhoku region should include population and aging trends into their reconstruction plans. Furthermore, and in context of the case study, that would also relate to adjusted development strategies for both, urban design and transport planning, which covers the development of the entire prefecture and their municipalities.

A potential method of *how* to adjust the given transport system towards shrinking settlements and an aging society is seen in the combination of the Backcasting approach with the DTL-circle

The here presented methodology describes a desirable image of the future at first. In the given case study, this future image illustrates a transport system, designed in accordance to the goals of sustainable transportation and is therefore able to guarantee the need of all age and population groups. It includes the trends of aging and shrinking into its design. Based on the evaluation of the impact along the transport dynamics within the DTL-cycle.

FIGURE 0-4 | CASE STUDY AREA – MIYAGI



(Source: own illustration, based and adapted from Wegener & Fürst (1999) and Rodrigue, et al. (2009))

TABLE 0-2 | CITIES OF MIYAGI PREFECTURE

- *Sendai*
- *Higashimatsushima*
- *Ishinomaki*
- *Iwanuma*
- *Kakuda*
- *Kesennuma*
- *Kurihara*
- *Natori*
- *Ōsaki*
- *Shiogama*
- *Shiroishi*
- *Tagajō*
- *Tome*
- *Tomiya*

(Source: own illustration, based on Brinkhoff, 2017)

TABLE 0-3 | DISTRICTS, TOWNS AND VILLAGES OF MIYAGI PREFECTURE

- | | | | |
|------------------------------|---------------------------------|----------------------------------|--------------------------------|
| <i>Igu District</i> | <i>Kurakawa District</i> | <i>Motoyoshi District</i> | <i>Toda District</i> |
| - <i>Marumori</i> | - <i>Ōhira</i> | - <i>Minamisanriku</i> | - <i>Misato</i> |
| <i>Kami District</i> | - <i>Ōsato</i> | <i>Oshika District</i> | - <i>Wakuya</i> |
| - <i>Kami</i> | - <i>Taiwa</i> | - <i>Onagawa</i> | <i>Shibata District</i> |
| - <i>Shikama</i> | <i>Miyagi District</i> | <i>Watari District</i> | - <i>Kawasaki</i> |
| <i>Katta District</i> | - <i>Matsushima</i> | - <i>Watari</i> | - <i>Murata</i> |
| - <i>Shichikashuku</i> | - <i>Rifu</i> | - <i>Yamamoto</i> | - <i>Ōgawara</i> |
| - <i>Zaō</i> | - <i>Shichigahama</i> | | - <i>Shibata</i> |

(Source: own illustration, based on Brinkhoff, 2017)

THESIS AIM

The challenges and thus the research question is derived as follows:

How to design a regional transport system, which enhances the mobility of the elderly and can support a regions thrive in the face of uncertain future economic, social, and environmental shifts?

Sub Questions to answer the full width and depth of the main research question are:

- 1) What development objectives shall be applied for regions facing depopulation and aging?***
- 2) What are goals and targets of sustainable transport systems facing aging and depopulation?***
- 3) What are the main characteristics of urbanization in relation to aging trends in Miyagi?***
- 4) How does the case of Miyagi relate to other similar cases around the world, as well as in recent history or near future?***
- 5) What are the implications of these characteristics on the performance, sustainability, and resilience of a regional transport system?***
- 6) Which design requirements and principles should guide the redesign for this specific Japanese case?***
- 7) How can the insights gained from the Japanese case be generalized and applied to other countries/societies with comparable issues?***

Research Objective

The key objective of this thesis is to recommend certain designs for a regional transport system. This shall be based on innovative solutions capable to face a changing demand of an aging society, the shrinkage of settlements and to mitigate the impact of climate change.

Its purpose is to guarantee the mobility needs of all age and population groups and to support a regions thrive also in times of an uncertain future due to economic, social, and environmental shifts.

All of which will be applied and analysed along the case study of Miyagi.

In the end, not just the Miyagi prefecture, but many governments and policies of developed countries worldwide, have largely ignored the effects of aging, urbanization and depopulation on transport systems.

It is therefore, that existing transport systems all over the world seem inadequate to support the shrinking settlements and the striking proportional increase of elderly. A situation which is addressed in this work.

THESIS OUTLINE

The thesis is divided into five parts and based on the backcasting method as presented in the chapter before.

Part one – Introductory states the purpose of the thesis and consists of two chapters.

The first chapter introduces the research context and questions. Underlying theoretical and methodological framework is described before the outline of this thesis is presented at the end. The theoretical framework of the thesis describes the interaction of demand, transport system and land use. Each of the three is further explained regarding their underlying system mechanics. The methodological frame discusses the goals of sustainability in transport planning first before the backcasting approach is laid out, which is used to derive a transport system capable to live up towards the goals of sustainability.

Part two – Objectives, Goals and Targets elaborates further on sustainability for transportation. This part consists of two chapters and addresses the sub-questions 1 and 2.

Chapter 1 – Backcasting Step 1 lays out the general objective, scope and number of scenarios.

Chapter 2 – Backcasting Step 2 is elaborating on goals and targets of a sustainable transport system and their influence on mobility for all age groups. The global objectives of *Universal Access, Safety, Efficiency* and *Green Mobility* are introduced and cross-referenced to the goals of sustainability. Further, the temporal, spatial and substantive scope of the thesis is presented as well as the scenario choice is made. Objectives and concrete targets to each goal are pointed out.

These Goals, Objectives and Targets are the foundation for the scenario analysis later in the Thesis

Part three – Present System and External Factors describes the current transport system of the case study regarding its modal characteristics as well as its influential trends of shrinking and aging. Part three consists of two chapters and addresses the sub-questions 3 and 4.

Chapter 3 – Backcasting Step 3 elaborates the modes given in Miyagi.

Chapter 4 – Backcasting Step 4 elaborates on the two trends which influence the development of the Miyagi prefecture.

The effects of both are elaborated towards travel demand, transportation and land use. Those are pointed out along the case of East Germany.

Part four – Exploring the Future describes the potential development paths (scenarios) of how the transport system of Miyagi Prefecture could develop in the future. This section consists of three chapters and addresses the sub-questions 5, 6 and 7.

Necessary iterations are conducted in order to be consistent with the goals of sustainable transportation. But just the final iteration is presented within the thesis.

Chapter 5 – Backcasting Step 5 is carrying out the scenario analysis. Two scenarios, a *projective (forecasting)* and a *prospective (backcasting)* scenario are introduced and elaborated. Resulting in file-of-actions and a general development plan for the case study.

Chapter 6 – Backcasting Step 6 focuses on the implementation of the requirements in order to achieve the prospected scenario. The chapter elaborates on transport concepts and derived transport designs in order to achieve this aim.

Chapter 7 – Backcasting Step 7 elaborates an impact analysis of the prospected and developed transport system design in respect to the goals of sustainability.

Part five – Generalization, Discussion, Conclusion & Recommendation is the final part of the thesis and consists of three chapters.

The chapter on Generalization first summarizes the undertaken analysis and evaluates the backcasting method as a general application for municipalities worldwide.

The chapter on Discussion reflects on the outcome of the backcasting iteration process. It discusses the challenges which need to be faced in order to implement sustainable transport designs for the elderly and describes what can be applied to other areas in the world who face an aging society as well as urbanization and depopulation trends.

The chapter on Conclusion is explicitly answering each of the research questions with a concluding statement.

The chapter on Recommendations lists and explains designs which can be applied but also insights on potential further research in the field of sustainable transport design and backcasting as method to face the challenges of transport planning of the 21st century.

PART TWO

1 DESIGN OBJECTIVES

Mobility is not just an essential precondition for the social participation of people, also economic activities significantly depend on the design of traffic and transportation. In the light of demographic change, increasing urbanization and climate change, it is the challenge to guarantee the needs of mobility of all and to design sustainable transport systems at the same time. In this context, innovative solutions obtain increasingly important.

The following subchapter 1.1 describes the purpose of the thesis by laying out its main objective.

Furthermore, the substantive, spatial and temporal scope of the backcasting analysis is defined in subchapter 1.2 as well as the number and type of scenarios introduced and explained subchapter 1.3. The chapter closes with a short discussion and conclusion in subchapter 1.4.

1.1 OBJECTIVE

The key objective of this thesis is to recommend certain designs of a regional transport systems which shall be based on innovative solutions capable to face changing demands due to an aging society, resilient towards shrinking settlements and mitigate climate change. Its higher goal is to guarantee the mobility needs of all age and population groups and to support a regions thrive at all times. Also, in times of an uncertain future with economic, social, and environmental shifts, due to aging and shrinkage.

The Miyagi prefecture is chosen as case study within this thesis, because of the prefectures opportunity to reconstruct settlements and their transport systems under the concepts sustainability and the compact city. As mobility is the key for societal interaction, also with a high age, the rebuild of settlements and transport infrastructure shall create age-friendly urban environments and barrier-free transportation in order to provide transport possibilities which are less demanding on private motorization. This main objective can be further divided into a theoretical and practical objective:

- *The **theoretical objective** of this thesis is to design a sustainable transport system to reassure the mobility of all people of all age groups, by including major trends, aside the goals for sustainable transportation, into the development methodology used for the design of a transport system.*
- *The **practical objective** of this thesis is to contribute to the improvement of the transport systems of the Miyagi prefecture, by analyzing the impact of the proposed design measures on social, economic, and environmental aspects.*

1.2 SCOPE

The different scopes of this thesis are derived as follows:

Substantive Scope: The transport system is the central scope and point of view within this thesis. Focus is put on transport modes for passenger services operating on land in an urban and rural environment and their related infrastructural design measures.

People, and their behavior, is understood and included as travel behavior and transport demand which thus influences the transport system.

The thesis includes and follows the goals of Sustainable Transport Planning as a key driver for the design of the proposed transport system.

Proposed measures are either focusing on infrastructure design changes (such as roadways, tracks and access and egress points) or service network design changes (lines and frequencies).

The study focuses on elementary as well as system related designs, such as street design (as element of a network) or network design (as network system).

Temporal Scope: The scenario study target is the year 2040 with mid-point of the year 2030, beginning with the data available from 2015. The time horizon is chosen to be long term in order to derive a sustainable transport system for decades and since changing on build environment within transport and land use usually is slow (see DTL-cycle)

Geographic Scope: The Miyagi prefecture, located in the north of Japans main island Honshu is chosen as study area within this thesis as well as the following transport related systems:

- *Motorway and major roadway network of Miyagi prefecture*
- *Railway network and its service quality within the Miyagi prefecture*
- *Metro network and service quality of Sendai*
- *Regional Bus network and service quality of Miyagi prefecture*
- *Urban Bus network and service quality of local governments within the Miyagi prefecture*

Only line-bound Public Transportation is considered within this thesis. Potential future developments as demand responsive automated vehicles are not considered. This is justified by its uncertain technological availability as well as its unknown effect towards disaster resiliency and impact on social segregation.

Relevant transport services outside the study area are considered constant and are not evaluated.

1.3 SCENARIOS

According to the Backcasting approach provided by Geurs & van Wee (2004, p. 48) two kind of scenario can be distinguished. A *projective* and a *prospective* scenario. Both will be performed within this thesis in a qualitative approach. Both scenario types are in general described as follows:

The current state and situation is the starting point of a **projective scenario**. It extrapolates current trends and build future images. The construction of a projective scenario can also be named as **forecasting**. For instance, developing estimation on future populations are based on forecasting. (Geurs & van Wee, 2004)

On the other hand, **prospective scenarios** start at a possible or desired situation in the future. This future is usually described by goals and targets which are set and established by assumed events between the current and future situation. The construction of a prospective scenario can also be named as **backcasting**. Backcasting holds the capability to highlight discrepancies between the current and desired future and can incorporate large and even disruptive changes. (Geurs & van Wee, 2004)

Within this thesis, both scenarios are described as follows:

Central core of this thesis are two scenarios which both target the year 2045, with an in-between target of the year 2035.

The *first scenario*, the **projective** scenario is set to extrapolate the current trends within the population, transport system and land use of Miyagi. Aim is to build a future image of the prefectures transport and land use for the year 2045.

The *second scenario* is the **prospective** scenario. It is set to describe the transport system and land use patterns which fulfills the goals and targets of sustainable transportation and is built upon the before performed projective scenario. It highlights the discrepancies between both scenarios, with the aim to illustrate where large, disruptive changes have to take place in the current system.

1.4 DISCUSSION & CONCLSION

Elementary contribution of this chapter was to describe the overall research purpose in further detail. This has been done by dividing the research **objective** into a theoretical and practical objective.

Furthermore, setting a **scope** towards *substantive*, *temporal* and *geographic* aspects helped to frame the research's content which makes it comparable towards other or potential further studies.

The introduction of **scenarios** was already given in the introduction, but a further detail on them gave an overview over the applied methodology as well as its specialization towards the case study.

In the end, this chapter is set as a compact overview over the research's purpose, scope and potential application of its underlying methodology.

This thesis is applying the 7 step backcasting approach of Geurs & van Wee (2004) very literally, which also let to the implementation of this chapter. It can be concluded that in further studies a sufficient introduction chapter does cover the aim of this chapter. Nevertheless, it sets out a sufficient starting point for the following chapters of this work.

2 GOALS

The task of a sustainable traffic and transportation is to ensure that various mobility needs are met in the best possible way while undesirable side effects are reduced to an acceptable level at the same time. Within its given framework of policies, the region or settlement of the future is one which is able to succeed in that aim and maintain sustainability in the long term.

This chapter introduced and describes the goals and objectives of sustainable transport planning. It is based on and refers to the work of Litman, the sustainable development Goals derived by the *United Nations* and the contribution to sustainable objectives by the *Sustainable Mobility for All (SuM4All)* initiative. It therefore is a short qualitative literature review of the given insights on sustainable developments in transportation currently available and is limited to the general understanding of sustainability to balance *social, economic* and *ecological* aspects of transportation. However, one addition is considered

The following subchapter 2.1 introduces the work of Litman and his definition on sustainable transportation and his categorization of *goals, objectives* and *targets*. The upcoming subchapter 2.2 on Objectives refers to the work of the *United Nations* but mostly to the *Sustainable Mobility for All (SuM4All)* initiative and their identified four objectives towards sustainable transportation. Goals and Objectives based on the definitions by Litman and the *SuM4All* initiative have been combined in subchapter 2.3. Subchapter 2.4 adds the dimension of *Design Quality* as the resulting product, of sustainable development and subchapter 0 indicated a guideline on how sustainable transportation can be reached. This chapter ends with a short conclusion in subchapter 2.6.

2.1 SUSTAINABLE TRANSPORTATION GOALS

The better *mobility needs* are met by a transport system, the higher the *attraction* of an area becomes. Societies invest multiple resources into their transport systems, which however are in competition with other societal needs. Each resource has a monetary and/or societal price tag. And the costs for resources arise in the process of political negotiations and differ from region to region. Furthermore, those price tags are unstable in the course of time caused by change of the circumstances. Therefore, the technical possible scope of action is limited to the feasible, which is determinate by societies and their politics. (Litman, 2016)

Key objective of transport planning is to guarantee the ***needs of mobility of all age and population groups***; its responsibility to support a region thrive considering an uncertain future with economic, social, and environmental shifts due to ***demographic*** and ***climate change***. (see chapter 1)

Overall aim of sustainable transportation is to “*maintain our current generations need on transportation but without causing great or irreparable harm to future generations throughout the world*” (Litman, 2016).

The solution is seen by in the “*balance between social, economic and environmental aspects*” and the interaction of all three aspects in order to reach sustainability. (Litman, 2016)

The Goals of sustainability and their objectives as they were derived by Litman are presented in the Table 2-1. Each sustainability goal is fit into its own aspect of sustainable transportation, although they often overlap and influence each other. Pollution for example is considered an environmental matter, but it affects human health (*social*) as well as the fishing and tourism industries (*economic*). (Litman, 2016)

Within this thesis, a ***goal*** is understood as the ultimate achievement and an ***objective*** as the way to achieve a goal. ***Indicators***, in this document, represent quantitative measurable objects that need to be achieved and ***targets*** show how indicators shall develop.

2.2 GLOBAL OBJECTIVES

Similar to Litman (2016) the High-Level Advisory Group on Sustainable Transport of the United Nations defined Sustainable Transportation as “*the provision of services and infrastructure for the mobility of people and goods – advancing economic and social development to benefit today’s and future generations – in a manner that is safe, affordable, accessible, efficient, and resilient, while minimizing carbon and other emissions and environmental impacts.*” (United Nations, 2016, p. 10)

Therefore, the *Global Mobility Report 2017* posits that mobility should have four attributes it should be design after. It should be *equitable, efficient, safe and climate responsive*. Achieving these four objectives will ensure that mobility needs of the current generation and will not be met at the expense of future generations. These four global objectives are defined as follows: (SuM4All, 2017)

- *Equity and inclusivity are at the heart of **Universal Access (UA)**. This objective accounts for distributional considerations and places a minimum value on everyone’s travel needs, providing all, including the vulnerable, women, young, old, and disabled, in both urban and rural areas, with at least some basic level of access through transport services and leaving “no one behind.”*
- *The **Safety (SA)** objective aims to improve the safety of mobility across all modes of transport by avoiding fatalities, injuries, and crashes from transport mishaps.*
- *The **Efficiency (EF)** objective seeks to ensure that transport demand is met effectively and at the least possible cost.*
- *The **Green Mobility (GM)** objective aims to address climate change through mitigation and adaptation, and to reduce both air and noise pollution.*

2.3 MERGING

Within this thesis, these four global objectives, as described in the *Global Mobility Report 2017*, are combined with the transport sustainability goals and objectives as provided by Litman.

Each of Litman’s goals and objectives was linked towards one of the four global objectives derived by the Sustainable Mobility for All initiative. Aim is to indicate the relationship between goals on the one hand and their influence on the objectives of *efficiency, accessibility, safety and climate responsiveness* on the other.

In order to distinguish the objectives of Litman and the SuM4All initiative, the later ones are referred to as “*objective groups*” within this research.

Litman’s sustainability goals and their objectives as well as the four transportation objectives of the global SuM4All initiative are combined and presented in the Table 2-1 (p. 15).

The objective groups structure the sustainability objectives of Litman into four objective groups makes it easier to vary aspects between physical and operational. It organizes and grasps the wide range of tasks which need to be archived in order to reach the goals of sustainability.

Each objective fits into its own objective groups, although they often overlap and influence each other. Sticking with the before introduced example of Pollution, which is mostly considered an environmental matter and therefore related towards *Green Mobility (GM)*. However, it affects human health and therefore their *Safety (SA)* as well as the fishing industry, which is linked to technological *Efficiency (EF)*.

A more detailed version of table Table 2-1 is given in Appendix 01 (p. III). The appendix version is expanded by development indicators and their targeted direction which shall be referred to as the foundation of transport development.

The here presented summation of development objectives and targets are the strategic foundation of this research and transport design shall be aligned and guided towards it.

TABLE 2-1 | SUSTAINABILITY GOALS AND OBJECTIVES

Sustainability Goals	Objectives	Objective Group
I. Economic		
<i>Economic productivity</i>	<i>Transport system efficiency.</i>	<i>EF</i>
	<i>Transport system integration.</i>	<i>UA</i>
	<i>Maximize accessibility.</i>	<i>UA</i>
	<i>Efficient pricing and incentives.</i>	<i>EF</i>
<i>Economic development</i>	<i>Economic and business development</i>	<i>UA</i>
<i>Energy efficiency</i>	<i>Minimize energy costs, particularly petroleum imports.</i>	<i>EF</i>
<i>Affordability</i>	<i>All residents can afford access to basic (essential) services and activities.</i>	<i>UA</i>
<i>Efficient transport operations</i>	<i>Efficient operations and asset management maximizes cost efficiency.</i>	<i>EF</i>
II. Social		
<i>Equity / fairness</i>	<i>Transport system accommodates all users, including those with disabilities, low incomes, and other constraints.</i>	<i>UA</i>
<i>Safety, security and health</i>	<i>Minimize risk of crashes and assaults</i>	<i>SA</i>
	<i>Support physical fitness.</i>	<i>SA</i>
<i>Community development</i>	<i>Help create inclusive and attractive communities.</i>	<i>UA</i>
	<i>Support community cohesion.</i>	<i>UA</i>
<i>Cultural heritage preservation</i>	<i>Respect and protect cultural heritage.</i>	<i>UA</i>
	<i>Support cultural activities.</i>	<i>UA</i>
III. Environmental		
<i>Climate stability</i>	<i>Reduce global warming emissions</i>	<i>GM</i>
	<i>Mitigate climate change impacts</i>	<i>GM</i>
<i>Prevent air pollution</i>	<i>Reduce air pollution emissions</i>	<i>GM</i>
	<i>Reduce exposure to harmful pollutants.</i>	<i>GM</i>
<i>Prevent noise pollution</i>	<i>Minimize traffic noise exposure</i>	<i>GM</i>
<i>Protect water quality and minimize hydrological damages</i>	<i>Minimize water pollution.</i>	<i>GM</i>
	<i>Minimize impervious surface area.</i>	<i>GM</i>
<i>Open space and biodiversity protection</i>	<i>Minimize transport facility land use.</i>	<i>EF</i>
	<i>Encourage compact development.</i>	<i>EF</i>
	<i>Preserve high quality habitat.</i>	<i>GM</i>

(source: own illustration based on Litman, 2016 and SuM4All, 2017)

2.4 DESIGN QUALITY

Sustainable transportation is based on the interaction of *economic, social* and *environmental* aspects.

However, the quality of *design* is not understood as an own aspect of sustainability. It is rather seen as the concoction out of the balanced application of the first three.

There is of course a lot talk about sustainable urban design. In spatial planning and design, the very general sustainability aspects of the 'triple bottom line' consisting of the three P's: *people, planet* and *prosperity* are translated into territorial interventions seeking balance and synergy.

Within the context of sustainable Building Duijvestein (2004) added *project* (i.e. *design*) as the fourth aspect of sustainability. While economic, social and environmental aspects can put in a triangle, the fourth aspect of design is added on top, transforming the triangle into a three-dimensional tetraeder as shown in Figure 2-1 (van Dorst & Duijvenstein, 2004).

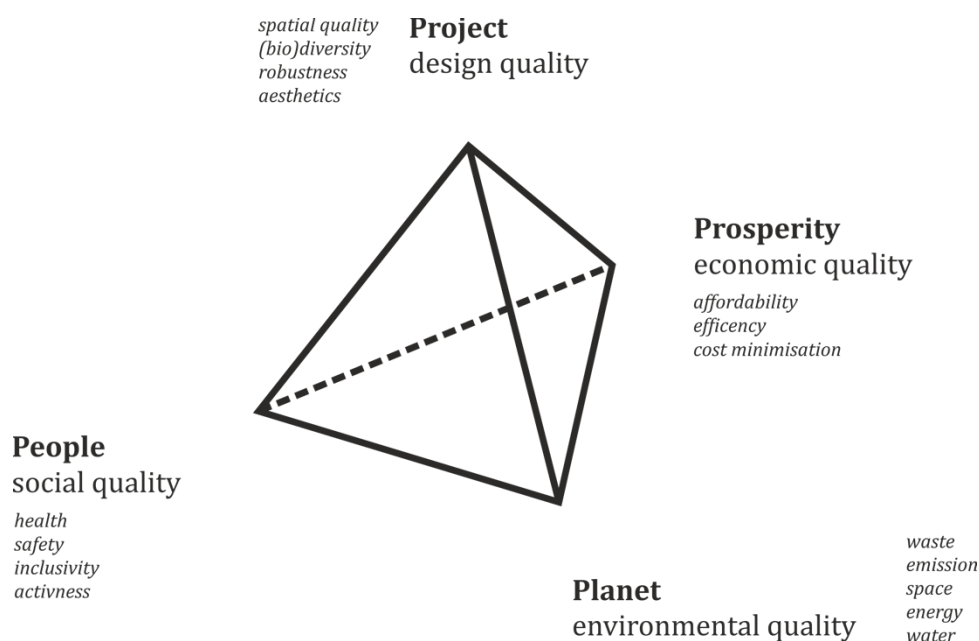
Within this thesis, *design quality* is considered as the fourth aspect of sustainable transportation. Resulting in a tetraeder similar to the one Duijvestein introduced. (van Dorst & Duijvenstein, 2004)

Each aspect of *design* is related to the quality of implemented transport infrastructure and services. A selection of what it concludes in the field of transportation is listed as follows:

- **Aesthetics** relates to the appearance of stops, station and carriageways.
- **Robustness** towards the mode's technical implementation and peoples demand.
- **Spatial quality** towards infrastructural claim of space and modal noise pollution.
- **Biodiversity** towards modal and infrastructural impact into habitats.

The *design quality* of transportation therefore describes the quality of all functionally linked components with the transport sector and adjacent fields of concern. It considers the functionality, usability and user friendliness of each transport mode and the entire system, without denying its impact towards the adjacent disciplines.

FIGURE 2-1 | FOUR P TETRAEDER



(source: own illustration based on van Dorst & Duijvenstein, 2004)

2.5 GUIDELINE

Means to enhance sustainability within the field of transportation is seen in the **“Avoid-Shift-Improve”** approach. This approach is based on the goals of sustainable transportation and shall be understood as a guideline for the development of such.

Avoiding, Shifting and Improving are defined as follows: (United Nations, 2016, p. 16)

- **Avoiding** inefficient or unnecessary travel or transport, where appropriate, e.g. by improved and integrated urban planning, compact city form, transport demand management, less complex and extended supply chains, and e-communication options (mobile phone use, teleworking),
- **Shifting** travel/transport to improve trip efficiency through most efficient or environmentally friendly mode or combination of modes, capable of meeting the travel/transport needs, and/or shifting to off-peak travel, and
- **Improving** the environmental performance of transport through technological, operational, regulatory or pricing, and/or infrastructure improvements to make transport vehicles and equipment and the provision of transport more energy efficient and less carbon intensive

As part of this thesis, the same guideline will lead the connectional design of a sustainable transport system within the Miyagi prefecture:

- *Mainly motorized trips shall be **avoided**.*
- *Mode choice shall be **switched** towards active modes or modes of public transportation.*
- *The infrastructure of active modes and public transportation shall be **improved**.*

2.6 DISCUSSION & CONCLUSION

This chapter defines the qualitative goals, objectives and target of sustainable transportation with the aim to describe them as *the* strategic foundation for the future development of traffic and transport worldwide. If not for the world, then at least for this case study.

Main focus is on the *sustainable transportation goals* discussed by Litman (2016), *sustainable development objectives* provided by the Sustainable Mobility for All initiative (SuM4All, 2017) and the three step *guideline* for sustainable transport development pointed out by the United Nations (2016).

The content of all three sources was introduced, sorted and connected with the aim to fulfill derived qualitative targets of further developments. All three sources were combined and the result is seen as the strategic foundation of this thesis in Table 0-1 and Appendix 01.

The aspect of *design* adds an additional layer towards sustainability as it describes the quality of the realized project.

In the end, all goals and objectives underlie multiple influencers, especially in transportation and urbanism. Most of which are derived by societal and political conditions, which are defined in political decision-making processes. Most of them therefore, are to be understood as external factors, which influence the development of transport systems and land use.

Thus, these goals relate to concrete requirements which have to be implemented through the adequate spatial implementation of transport modes.

PART THREE

3 TRANSPORT SYSTEM – THE PRESENT SYSTEM

The current transport system is the result of a development, influenced by technical possibilities, planning approaches and political priorities which changed over the course of time.

Within this chapter, the focus is laid on the given transport modes and their interaction which in turn form the overall transport system. The available modes are of fundamental importance towards the quality of the systems service in order to cope with the given and possible transport demand and their impact towards the location of activities.

The evaluation is undertaken considering the elements of the *Transport System (TS)* segment of the DTL-feedback circle.

This is done as foundation for the development of an age-friendly but also age-independent transport system which is aiming for stainability and reliability in a region of economic change.

The identified available Transport Modes within the Miyagi prefecture are as follows:

- **National Railway – Bullet Train**
- **Regional Railway**
- **Subway**

- **National Bus**
- **Regional Bus**
- **Bus Rapid Transit**
- **City Bus**

- **Private Vehicle**
- **Cycling**
- **Walking**

3.1 TRANSPORT SUPPLY – TRANSPORT SYSTEM

To make clear decisions towards a sustainable and multi-modal design of the Miyagi transport system the knowledge of modal specific characteristics of the given transport modes is required.

The usage of combined modes, as of *railways* and *cycling*, is an important aspect to consider. As part of this thesis, combined transport modes are not considered separately. On reason therefore is that key factors, influencers and effects cannot be assigned clearly. Inter-modal transportation is also not understood as an additional transport mode, rather as the result of an adequate and sensible use of the established transport modes according to their characteristics and advantages. (Weidmann, et al., 2011)

In order to complete this picture, the given transport systems will be typified and classified as foundation for further considerations. This procedure is based on Weidmann, et al. (2011) who compared the different characteristics of transport modes in order to derive their most efficient area of application for Swiss agglomerations.

The appearing variety of transport modes is large. However, Weidmann, et al. (2011) conclude that all relevant system characteristics derive from the following four attributes which are listed below:

- **Own vs. Mixed-used** carriageway
- **Track vs. Non-infrastructural** guidance
- **Collective vs. Individual** transportation
- **Motorized vs. Non-motorized** power

Towards each combination of possible attributes, a list of *system characteristics* can be derived from and associated to. All of which is listed in Table 3-1 (p. 20). The following three aspects can be concluded already after over-viewing Table 3-1:

- 1) *No transport mode has just advantages or disadvantages.*
- 2) *Within each aspect group exists considerable scope for their specific design.*
- 3) *A sustainable implementation and coverage can just be achieved with a coordinated application of multiple transport modes and their related services.*

Within the following step, the transport modes, which developed themselves and maintained their existence in the Miyagi prefecture are sorted, based on their system characteristic, and listed as represented in Table 3-2 (p. 20).

The following subchapters 3.2 and 3.3 are further elaborating on the modes established in the Miyagi Prefecture and their general system characteristics. All of the sorted and encountered towards the four attributes of transport mode.

TABLE 3-1 | QUALITATIVE SPECIFIC CHARACTERISTICS PER TRANSPORT MODE CATEGORY

		Own Carriageway		Mixed-used carriageway	
		Track guided	Non-guided	Track guided	Non-guided
Collective	Motorized	<i>P: high V: fast R: reliable A: low F: inflexible E: energy saving S: high \$I: high \$O: high</i>	<i>P: high V: relative fast R: reliable A: low F: relative flexible E: energy saving S: high \$I: medium \$O: medium</i>	<i>P: medium V: slow R: relative reliable A: low F: relative flexible E: energy saving S: medium \$I: medium \$O: medium</i>	<i>P: medium V: slow R: relative reliable A: low F: relative flexible E: energy saving S: medium \$I: low \$O: low</i>
	Non-motorized	<i>Does not exist</i>	<i>Does not exist</i>	<i>Does not exist</i>	<i>Does not exist</i>
Individual	Motorized	<i>Does not exist</i>	<i>P: high V: fast R: relative reliable A: high F: very flexible E: energy intensive S: medium \$I: high \$O: high</i>	<i>Does not exist</i>	<i>P: medium V: slow R: relative reliable A: medium F: very flexible E: energy intensive S: medium \$I: low \$O: low</i>
	Non-motorized	<i>Does not exist</i>	<i>P: high V: very slow R: reliable A: low F: very flexible E: non S: high \$I: low \$O: low</i>	<i>Does not exist</i>	<i>P: high V: very slow R: reliable A: low F: very flexible E: non S: low \$I: low \$O: low</i>

P: Performance; **V:** Velocity/speed; **R:** Reliability; **A:** Area/spatial need; **F:** Flexibility; **E:** Energy consumption; **S:** Safety; **\$I:** Investment costs; **\$O:** Operational costs

(source: own illustration, based on Weidmann, et al., 2011)

TABLE 3-2 | OVERVIEW OF AVAILABLE TRANSPORT MODES – MIYAGI

		Own Carriageway		Mixed-used carriageway	
		Track guided	Non-guided	Track guided	Non-guided
Collective	Motorized	<i>Railway – National Railway – Regional Subway (special systems)</i>	<i>Bus Rapid Transit BRT</i>	<i>(Tramway) (LRT)</i>	<i>National Bus Regional Bus City Bus</i>
	Non-motorized				
Individual	Motorized		<i>Private Vehicle Motorbike</i>		<i>Private Vehicle Motorbike</i>
	Non-motorized		<i>Pedestrian Cyclist</i>		<i>Pedestrian Cyclist</i>

Modes in brackets () are listed in order to be complete and do not operate in the Miyagi prefecture.

Tramway (or Light Rail Transit – LRT) is listed for the sake of completeness, since this mode is not established anymore in the Miyagi Prefecture.

Bus Rapid Transit (BRT) and City Bus are basically the same when coming from a technological point of view. Their difference lies in the manifestation of the separate carriageway for BRT systems, which highly influences vehicular velocity with further positive impacts on modal performance and operational cost. Both are therefore evaluated separately, due to their systematic manifestation.

(source: own illustration and characterization, based on Weidmann, et al., 2011)

3.2 COLLECTIVE TRANSPORTATION

Collective transportation provides and combines a variety of different transport modes in order to support the entire spectrum of transport needs. Modes are diverse and include low- and high-capacity vehicles such taxis, single or bi-articulated buses and a variety of trains. It is spatial and energy efficient, safe and secure as well as affordable for everyone.

Miyagi's public transport system is mainly railways based and supported as well as challenged by prefectural bus services. Nevertheless, the trains and busses within Miyagi are the classic collective modes of public transportation and bundle the given demand for transportation.

3.2.1 COLLECTIVE TRANSPORTATION – GUIDED

Railways

Miyagi's railway network consists mainly of radial lines which are oriented towards Sendai Station as its central hub. Other major hubs or transfer stations are *Furukawa* (located in *Osaki*), *Kogota* (*Misaki*) and *Ishinomaki*. (Miyagi Prefectural Government, 2013)

The *Tōhoku -Shinkansen* runs through the Miyagi prefecture connecting *Tokyo* with the Tōhoku region and Hokaido. The entire track is grate separated and runs mostly on a viaduct in North-South direction. The prefecture is accessed via four stations: *Sendai*, *Shiroishi-Zaō* (located in *Shiroishi*), *Furukawa (Osaki)* and *Kurikomakogen Station (Kurihara)*. All accessible via escalators and elevators, and level boarding is made possible towards the trains. Each stop is interconnected towards local public transportation, taxi services as well as drop-off zones for private motorization. Each bullet train stops at Sendai which makes it the most frequent served *Shinkansen* stop within the prefecture. The other stops are served less frequent. (Miyagi Prefectural Government, 2013)

Most settlements in the prefecture are located along and are connected via a railways service. However, the most frequent services are provided within the *Sendai Metropolitan Employment Area (Sendai MEA)*.

Two national rail services, *nine* regional train services and, *two* regional BRT services operating in Miyagi. 10 out of given 11 services are operated by *JR East*. The only privately-owned service is the *Abukuma Express Line*. (Miyagi Prefectural Government, 2013)

Two urban railway system operate in the municipality of Sendai as *Sendai Subway*. The *Namboku Line*, operating in North-South direction, opened in July 1987, while the *Tozai Line*, operates from East to West opened in December 2015. (Sendai City Transport Bureau, 2018)

3.2.2 COLLECTIVE TRANSPORTATION – NON-GUIDED

Busses

Miyagi's bus services operate in-between and sometimes parallel towards the prefecture's railway network. (Miyagi Prefectural Government, 2013)

Own infrastructure is mostly limited towards stops and their implementation. A bus service therefore is flexible to place and adjust, which is advantage and disadvantage at the same time. Design and quality of stops and vehicles highly depend on the demanded service and only a few provide level boarding. Busses mostly operate in common traffic and therefore do not significantly impact the urban scape or people's mode choice. (Miyagi Prefectural Government, 2013)

A city bus mainly operates in an urban environment and serves to provide access towards all areas of the settlement. City busses serve as distributor, collector and feeder towards urban quarters and transport modes with higher capacity. (Miyagi Prefectural Government, 2013)

A Prefectural Bus¹ inter-connects agglomerations as well as each settlement with the modes of higher capacities (i.e. regional railways). Depending on the size of a settlement one or more stops per settlement are served. Stop density and average speed vary strongly but is by far below the average of regional railways. (Miyagi Prefectural Government, 2013)

National and Regional² Buses are long distance bus services which interconnect prefectures or provide direct services to major national destinations, such as Narita Airport. Those Busses stop at very few places and mostly at transport hubs of each settlement. (Miyagi Prefectural Government, 2013)

¹ Prefectural Bus services shall be understood as comparable Regional Bus services of Europe.

² Regional Bus services are here referred to as services, which take place within the Tōhoku Region.

3.3 INDIVIDUAL TRANSPORTATION

Individual transportation can mainly be derived into two major transport categories, which drastically differ from each other. Motorized and non-motorized modes of individual transportation. The first mainly refers to the private vehicle or car but also includes motorbikes or scooters. The later relates mainly to walking and cycling but also include other forms such as longboards or Segway's. Depending if motorized or not, the spatial and energy efficiency, safety and security as well as affordability for everyone varies dramatically.

Nevertheless, all of them interact in a limited amount of space which is given by the Miyagi roads.

3.3.1 INDIVIDUAL TRANSPORTATION – MOTORIZED

Private Motorization / Car

The automobile is the mode of transport which demands the highest entrance investment and highest personal qualification for its usage. Based on these characteristics, a certain group of people will always exist who cannot access this mode.

Private motorization provides the highest form spatial accessibility when affordable due to its speed and dense network of streets. However, it is also the most inefficient form of transportation, due to its high demand on (fossil) resources per capita and its infrastructural impact on land use.

Miyagi's well-developed road network consists of national, prefectural and municipal roads and can be considered as complete. Mostly so, the provided road space for private owned vehicles is prioritized over other mostly non-motorized forms of transportation.

The prefectures network of Expressways mainly consists of radial roads which are oriented towards Sendai resulting in an expressway ring road around the city.

In total 16 national roads connect the Settlements of Miyagi and adjacent prefectures. National roads can be considered as distributor and collector roads of the network. Municipality roads usually fulfill the function to access an area of quarter. Nevertheless, the separation of road functions into connector, distributor or access roads is blurry due to street designs which are not homogeneous.

Access roads, mostly municipal roads, are naturally calmed as they're often very narrow. It's difficult for two cars to pass, few are straight, many have blind corners and sidewalks are uncommon. As a result, the road space is *shared* between pedestrians, cyclists, and automobiles.

3.3.2 INDIVIDUAL TRANSPORTATION – NON-MOTORIZED

Active modes

Active modes are healthy, silent and emission-free. They are the most natural and affordable modes of transport and most comfortable for short to medium distances. It is also a necessary component of the vast majority of public transport trips. And in comparison, it requires very less public space than the private automobile.

Walking and cycling are fundamental elements of sustainable transportation. Walking is, or can be, the most enjoyable and productive way of getting around provided that paths and streets are populated and desired activities (i.e. services and resources) conveniently located.

It also requires physical effort. Detours can be easily discouraged walking which is particularly sensitive to network density. A network of short routes and adequate blocks is therefore of importance for the interconnection of activities and public transportation.

Furthermore, active modes are highly sensitive to environmental weather conditions. Mostly so towards sun, wind and rain. Greater than in any other mode, topography influences the usage and range of bicyclist.

Cycling combines the convenience of door-to-door travel as well as the route and schedule flexibility of walking but increases the area of coverage. E-bikes (bicycles equipped with an electric engine) increase range and speed dramatically. This as well as conflicts with cars and pedestrians demand for a separate and exclusive infrastructure in the given road space.

Active modes activate streets and are the foundation towards public transportation. They are also the most vulnerable road users, and bicycles are also exposed to theft and vandalism. In comparison, the spatial separation of cyclist toward other traffic and transport participants is far less advanced as pedestrian paths within Miyagi's road network.

3.4 TRIP DECISION

Trip rate and degree of motorization in the *Sendai MEA* are listed in Table 3-3.

Within ten years, the citizens of the *Sendai MEA* undertake less trips, which is assumed to be related to the decrease in people going out which reduced by 1,10% over the same timeframe. The *actual number of trips* per person increased by 4.06% from 1992 to 2002. In the same time the *average* number of trips per person however, decreased by 0.10 trips. It is worth noting that a shrinkage of trips was undertaken in a time where the *Sendai MEA* was still growing in population size.

The degree of *private motorization* was found with 570 private vehicles per 1,000 inhabitants dating back towards the year of 2002. From 1992 to 2002 the degree of motorization increased by 8.50% leading to the fact, that on average every 2nd citizen of the *Sendai MEA* owns an automobile.

Based on expert judgement it is known, that the degree of motorization varies per statistical area and usually increases with a decrease of population density. The degree of motorization in the city of Sendai itself is therefore assumed lower as in the adjacent municipalities. It is also assumed, that the motorization outside of the *Sendai MEA* is even higher. Unfortunately, data to back up this assumption where unavailable.

3.5 MODE CHOICE

On average, the ratio of transport modes chosen by the citizens of the *Sendai MEA* is illustrated in Figure 3-1.

In total 56.2% of the trips are made by modes of private motorization, 53.5% use the car and 2.7% the motorbike. The modes of public transportation are chosen by 13.1%, 8.9% chose for rail and 4.2% for the bus. Active modes made 30.7% of the modal split of Sendai, which is 20.2% for walking and 10.5% for cycling.

The share on private motorized trips raised from 46,9% in 1992 to 53,5% in 2002. The increase in motorization as indicated above also lead to a higher usage of it. Much to the disadvantage for active modes. (-4%) and local public transportation (bus - 2%). Railways and cyclist remain their share, but due to lower trip numbers, is the actual demand also reducing.

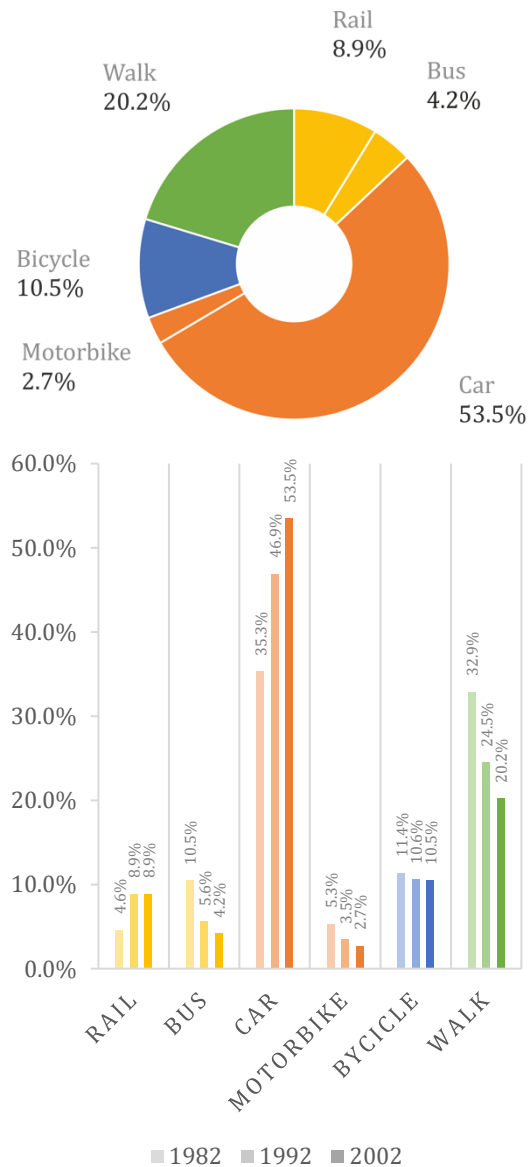
A view further back in time indicates a lower usage of private vehicles and a higher share of walking. Nearly one third of trips where undertaken by private vehicles while another third was done by walking. 20 years late, in 2002, the share of private motorization trips increased to more than 50% while walking decreased to about 20%.

TABLE 3-3 | TRIP RATE AND MOTORIZATION - SENDAI MEA

	1992	2002
Number of trips	3.45 mil/day	3.59 mil/day
Average trip per citizen	2.56 trips	2.44 trips
Average trip per going out citizen	2.99 trips	2.89 trips
Citizen rate who go out:	85.7%	84.6%
Motorization	485 Veh./ 1,000 Inh.	570 Veh./ 1,000 Inh.

(source: own illustration, based on City of Sendai, 2017; Miyagi Prefectural Government, 2013)

FIGURE 3-1 | MODAL SPLIT - SENDAI MEA



(Source: own illustration, based on Dimmer, 2017)

3.6 MODAL BASED SYSTEM CHARACTERISTICS

The performed qualitative characterization of the given transport modes still offers to identify major differences between them which is listed in Table 3-4.

TABLE 3-4 | QUALITATIVE MODAL SPECIFIC CHARACTERISTICS

<i>Mode</i>	<i>Pedestrian</i>	<i>Cyclist</i>	<i>Bus</i>	<i>BRT</i>	<i>Railway – Regional</i>	<i>Subway</i>	<i>Private vehicle</i>
Weight of Unit	<i>Very low</i>	<i>Very low</i>	<i>Low</i>	<i>Low</i>	<i>High</i>	<i>High</i>	<i>Low</i>
friction coefficient	<i>–</i>	<i>High</i>	<i>High</i>	<i>High</i>	<i>Low</i>	<i>Low</i>	<i>High</i>
Breaking distance	<i>–</i>	<i>Short</i>	<i>Short</i>	<i>Short</i>	<i>High</i>	<i>High</i>	<i>Short</i>
Stop on sight possible	<i>Yes</i>	<i>Yes</i>	<i>Yes</i>	<i>Yes</i>	<i>No</i>	<i>No</i>	<i>Yes</i>
Damage potential in case of emergency	<i>Low</i>	<i>Low</i>	<i>Low</i>	<i>Low</i>	<i>Big</i>	<i>Big</i>	<i>Low</i>
Operation by timetable	<i>No</i>	<i>No</i>	<i>Yes</i>	<i>Yes</i>	<i>Yes</i>	<i>Yes</i>	<i>No</i>
Dynamic signalization of carriageway	<i>Partially</i>	<i>Partially</i>	<i>Yes</i>	<i>Yes</i>	<i>Yes</i>	<i>No</i>	<i>Yes</i>
Dynamic security of carriageway	<i>No</i>	<i>No</i>	<i>No</i>	<i>No</i>	<i>Yes</i>	<i>Yes</i>	<i>No</i>
Inconspicuous of carriageway	<i>No</i>	<i>No</i>	<i>(No)</i>	<i>(No)</i>	<i>Yes</i>	<i>Yes</i>	<i>No</i>
Performance _[P/h] (comfort oriented)	<i>700</i> <i>–</i> <i>3,500</i>	<i>100</i> <i>–</i> <i>700</i>	<i>1,500</i> <i>–</i> <i>3,000</i>	<i>2,000</i> <i>–</i> <i>5,000</i>	<i>4,500</i> <i>–</i> <i>18,000</i>	<i>3,000</i> <i>–</i> <i>10,000</i>	<i>100</i> <i>–</i> <i>5,000</i>
Stop distance _[m]	<i>–</i>	<i>–</i>	<i>300</i> <i>–</i> <i>700</i>	<i>300</i> <i>–</i> <i>700</i>	<i>2,500</i> <i>–</i> <i>3,500</i>	<i>500</i> <i>–</i> <i>1000</i>	<i>–</i>
Travel speed _[km/h]	<i>5</i>	<i>12</i>	<i>20</i>	<i>20</i>	<i>40 - 50</i>	<i>30</i>	<i>30 - 60</i>
Personal qualification needed	<i>No</i>	<i>No</i>	<i>No</i>	<i>No</i>	<i>No</i>	<i>No</i>	<i>Yes</i>
Route knowledge needed	<i>Yes</i>	<i>Yes</i>	<i>(No)</i>	<i>(No)</i>	<i>(No)</i>	<i>(No)</i>	<i>Yes</i>
Quality of accessibility	<i>Very High</i>	<i>Very High</i>	<i>High</i>	<i>High</i>	<i>High</i>	<i>High</i>	<i>Low</i>
Reliability	<i>Medium</i>	<i>Medium</i>	<i>Low</i> <i>–</i> <i>Medium</i>	<i>Low</i> <i>–</i> <i>Medium</i>	<i>High</i>	<i>High</i>	<i>Low</i>
Safety/Security	<i>Low</i>	<i>Low</i>	<i>Medium</i>	<i>Very High</i>	<i>Very High</i>	<i>High</i>	<i>Low</i>
Temporal availability	<i>Very High</i>	<i>Very High</i>	<i>Medium</i> <i>–</i> <i>High</i>	<i>Medium</i> <i>–</i> <i>High</i>	<i>Medium</i>	<i>Medium</i>	<i>Very High</i>
Spatial availability	<i>Very High</i>	<i>Very High</i>	<i>Very High</i>	<i>High</i>	<i>Medium</i>	<i>Medium</i>	<i>Very High</i>

(source: own illustration, based on Weidmann, et al., 2011)

3.7 DISCUSSION & CONCLUSION

This chapter focuses on the given transport system within the Miyagi prefecture. This has been done by listing and sorting the given transport modes according to their system characteristics.

Furthermore, the modal split of the *Sendai MEA* was investigated in order to see how traffic and transportation developed over the last decades.

The analysis of the given modes is based on the possible combination of four attributes as described by Weidmann, et al. (2011). The results lead to the described system characteristics, which makes it possible to compare the given modes.

From a qualitative point of view, it can be concluded that no transport mode on itself offers just advantages or disadvantages. Within each aspect group exists considerable scope for their specific design. And a sustainable implementation and coverage can just be achieved with a coordinated application of multiple transport modes and services.

The current development of increased usage of private motorization within the *Sendai MEA* therefore can be seen as a development towards a mono-modal transport system within that area, causing the negative impact as the described system characteristics specify.

Related to distance and purpose, some transport modes are more suitable than others and a couple of possibilities exist to combine different modes with each other in order to combine their advantages. The usage of combined transport modes can therefore also be seen as result of an adequate application of them, assuming and requiring that all nodes and hubs for transfers offer an efficient and present service.

4 AGING & SHRINKAGE – EXTERNAL VARIABLES

This chapter elaborates further on the two major trends of *shrinking cities* and *aging societies*.

Shrinking mainly refers to the work Westphal (2008) who developed qualitative and quantitative criteria for the determination of adequate densities, from the point of view of city-technical infrastructure, which got differentiated based on urban typologies. Her study area is eastern Germany which suffered a severe population loss and demographic change after the reunification in 1990.

Aging is mainly referred to the work of Cui, et al., (2017) and Szeto, et al. (2017). While Cui, et al., provides a comprehensive and mostly qualitative overview of the work done in automobile oriented nations, Szeto, et al. offers a detailed insight into all travel behavioral importance. Their insights are included in subsection 4.3.

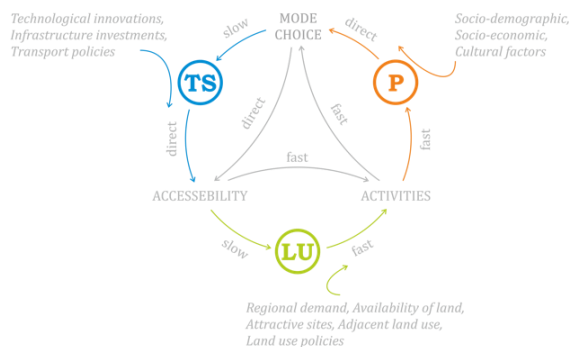
The both trends impact on the development of a transport system is discussed in subsection 4.4 and concluded in 4.5.

4.1 EXTERNAL FACTORS

The discussion of sustainable transportation must take place with an understanding of the larger trends of societal and technological development. External factors influence the segments of the DTL-feedback loop and as a result the development of a transport system and the usage of available land. (SuM4All, 2017)

Chorus (2012) indicated that activities are not only determined by land use characteristics. *Attitude, lifestyle* and *socio-economic characteristics* tend to have a much stronger influence on *travel behaviour* than land use patterns. Influencers

FIGURE 4-1 | EXTERNAL INFLUENCERS



(source: own illustration and adaptation, based on Chorus, 2012; and Litman, 2016)

In short, certain factors of the environment influence the feedback loop from the outside and have a major impact on the development of each segments of the DTL-circle. All of which are illustrated in Figure 4-1.

Aging is seen as an external factor which directly influenced on people’s behaviour. As a consequence, it is impacting mode choice since elderly have specific demands towards the given transport system. In the long run, aging therefore also changes the qualities of accessibility and impacts the attraction of places and the associated land use.

Furthermore, the problem of how to deal with an urban-rural integration as well as rural shrinkage of settlements is addressed.

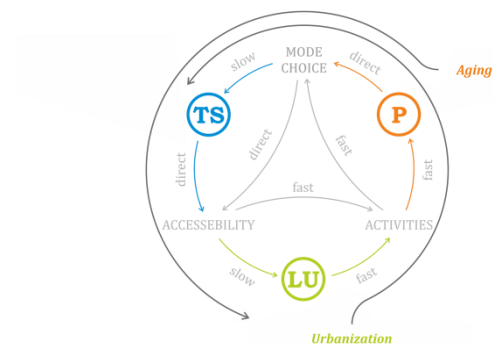
Urbanization is a broad field and mainly indicating an increase of urban population *at first*. This is either caused by an increasing birth rate or by people moving from the surrounding or far away countryside. *At second*, and with focus on developed countries, indicates aging in combination with low birthrates lead to continuous decline in population. These demographics combined with an increasing attraction of major cities, leads to the de-population of the countryside, as well as shrinkage of mid-sized cities.

In this context urbanization is further understood as the growth of major cities and the shrinking of mid-sized cities as well as the de-population of the countryside.

Urbanization is a trend and external factors which influencing the Land Use segment of the DTL-feedback cycle. It influences land use developments, changes the urban form and defines new urban structures. Those again influence activities of people which choose, and use transport systems to reach their activity of choice.

Both trends and their impact circle are illustrated in Figure 4-2 and further elaborated in the upcoming subchapters.

FIGURE 4-2 | INFLUENTIAL TRENDS



(source: own illustration and adaptation, based on Chorus, 2012; and Litman, 2016)

4.2 LAND USE UNDER SHRINKAGE

Population

The cities of the so called “new” federal states of Germany, had to face a far-reaching and multidimensional change after the country’s reunification. After the collapse of the socialist and central administered economic system of the *German Democratic Republic (GDR)*, a radical economic structural disruption took place, followed by a process of transformation and de-industrialization. Not only that economic mono-structured cities or regions were effected. Also, municipalities with a differentiated economic foundation had to face this development.

In the course of economic restructuring, almost 80% of all jobs in the agricultural sector were lost in relation to the entire territory of the new federal states. A similar trend took place in the military sector as well as political administrative institutions. Immediately after the reunification, a significant population loss took place, which were initially due to a significant death toll and a job-related migration towards the “old” federal states.

Between 1993 and 1997 the population loss was dampened by migration gains towards the new federal states, which even resulted in a migration gain for this period (Westphal, 2008). By the end of the decade, the inner German migration processes, which is characterized by selective migration of young, qualified people, again became significant for the municipal population decline again. (Westphal, 2008)

The combination of these factors can be summarized with the following three aspects: (Westphal, 2008)

1. *Economic structural change,*
2. *Education or employment related migration,*
3. *Demographic change*

All of them lead to a systematic urban shrinkage, which in this form represents a historically unique phenomenon in Germany. (Westphal, 2008)

Density

Almost all eastern German cities were confronted with declining numbers of inhabitants and jobs in a very short time. (Glock, 2007)

One of the most obvious urban structural consequences of the population loss was the high vacancy rate of apartments. The permanent lack of housing, typical for the GDR, reversed after the reunification. In 1990, 400,000 homes were uninhabitable due to a lack of government investment in the rehabilitation and maintenance. Between 1993 and 1998 the number of vacancies doubled, even to around one million. (Westphal, 2008)

Decisive factors of this vacancy dynamics were, the migration-related and natural population loss of the early 1990’s as well as the construction of approx. 800,000 rental properties and the renovation of old buildings, which collided with massive municipal employment cuts and ongoing local and long-distance migration patterns of inhabitants. (Westphal, 2008)

Many eastern Germans realized their dream of their own home in a peripheral location after the reunification of 1990. This construction boom in the surrounding areas of cities – as a kind of catching-up suburbanization of the new federal states – was accompanied and favored by the unattractive state of core cities as residential location. These inner areas were marked by decades of decline during the GDR era, since their typology were stemming from the bourgeoisie era and are not fitted for the socialist ideal. The necessary repair and modernization of the building fabric described above took a long time due to unclear ownership situations and lack of financial resources of the owners. (Topfstedt, 1988)

Due to these de-densification processes, the question of the appropriate density arises in a new context. Therefore, the *four* guiding concepts of the development of urban structures in shrinking cities derived and are presented in Appendix 11 (p. XV).

Development

The processes of suburbanization ran parallel to the de-urbanization of cities and therefore lead to a socio-spatial change in the eastern German urban landscape. These “new” characteristics were *dispersion* instead of *concentration* and structural destruction with simultaneous increase in urban area.

This reorganization of space lead to a type of social segregation. Defined by long-distance migration, especially of young, qualified people and the urban-suburban migration of families with high-income. Ultimately, the social composition of the population in shrinking communities changed. In particular, when housing vacancies was concentrated in a certain part of the city lead towards a social downwards spiral. *“Those who are too poor, too unqualified or too old to move away remain”* (Glock, 2007; Westphal, 2008)

Social development, in turn, affects the municipal budget and governmental support. Falling trade and income taxes weakening the already tense financial situation of eastern German municipalities. The simultaneously rising costs for coping with shrinkage were ultimately allocated to the remaining, mostly low-income inhabitants. (Westphal, 2008)

Restrictions due to shrinkage can also be found in the area of social and technical infrastructure. A serious loss of inhabitants and population density of the cities consequently lead to the closure of schools, shops, medical practices and other social facilities that are no longer needed. Another problem was the underutilization of the public transport network and over-dimensioning of cities technical supply and disposal system. (Westphal, 2008)

4.3 TRANSPORT DEMAND UNDER AGING

Aside the decline of population, the changing demographics due to aging has a major impact on traffic and transport demand. Despite a rise in specific mobility and increasing traffic participation of all age groups, a decline in ridership can be observed in the course of depopulation and age. This reduction in demand is caused, on the one hand, by a decline in the total population and, on the other hand, by a reduced occupation of the more mobile age groups, especially students and professionals. (Westphal, 2008)

Travel demand of the elderly dramatically differs from their younger counterparts. Szeto, et al. (2017) and Cui, et al. (2017) indicate, that the willingness and ability to drive is decreasing with and increasing age. This leads to a decreased travel activity, as well as shorter journey times and travel distances. (Szeto, et al., 2017; Cui, et al., 2017)

Table 4-1 illustrates the rates for motorized trips on a typical weekday for young adults and the three age groups of elderly for the Hong Kong area.

TABLE 4-1 | MOTORIZED TRIP RATE – HONG KONG

	Age Group			
	18-59	60-69	70-79	80+
Motorized trip rate	1,39	0,92	0,58	0,36
Decrease in motorized trip rate	-	-34%	-58%	-74%

The decrease in motorized trip rate is related in all three cases towards the age group of 18-59

(source: own illustration, based on Szeto, et al., 2017)

It clearly indicates the decrease of motorized trips as people age. Nevertheless, trip rates varied considerably across the different age groups indicating a strong reduction of trips as people age within the Hong Kong area.

Figure 4-3 (a) illustrates how trip purpose significantly varies between age groups in the Hong Kong area. Szeto, et al. (2017) discussed that the purpose of a trip changes significant from *mandatory* (school and work) to *optional* trips (household sustaining and leisure) as people age.

Throughout a lot of publications, it became clear, that the number of travel activities are related to age and that the mobility of people in general decreases as age increases.

However, van den Berg et al. (2011) found out that elderly in the Netherland have a higher average in social trips when involvement in associations and/or given with a higher education level. Full time work on the other hand resulted in fewer social trips. Gender, age and disabilities on the other hand, were found to have no significant effect on social trips of older adults. (Szeto, et al., 2017; Cui, et al., 2017)

Of course, elderly are not a homogeneous group and travel pattern therefore vary among subgroups. (Szeto, et al., 2017)

Figure 4-3 (b) illustrates the proportion of trips by journey time for different age groups and gender in the Hong Kong area. The finding revealed, that with an increase in age journey times reduce. Most of the elderly travelled for a short trip (for less than 30 minutes) of time, while their younger respondents made longer trips.

Szeto, et al. (2017) illustrated that during peak hours (7:00 – 10:00 and 17:00 – 20:00), the elderly traveled much less than at off-peak hours. Another observation is that elderly traveled more equally distributed during the afternoon off-peak time (10:00 – 17:00).

One explanation therefore is found in the avoidance of crowds. As well as because of retirement, when elderly can alter their trips start time to a more comfortable time of day Figure 4-3 (c) illustrates the trips start time of elderly over different hourly periods in a day. (Szeto, et al., 2017)

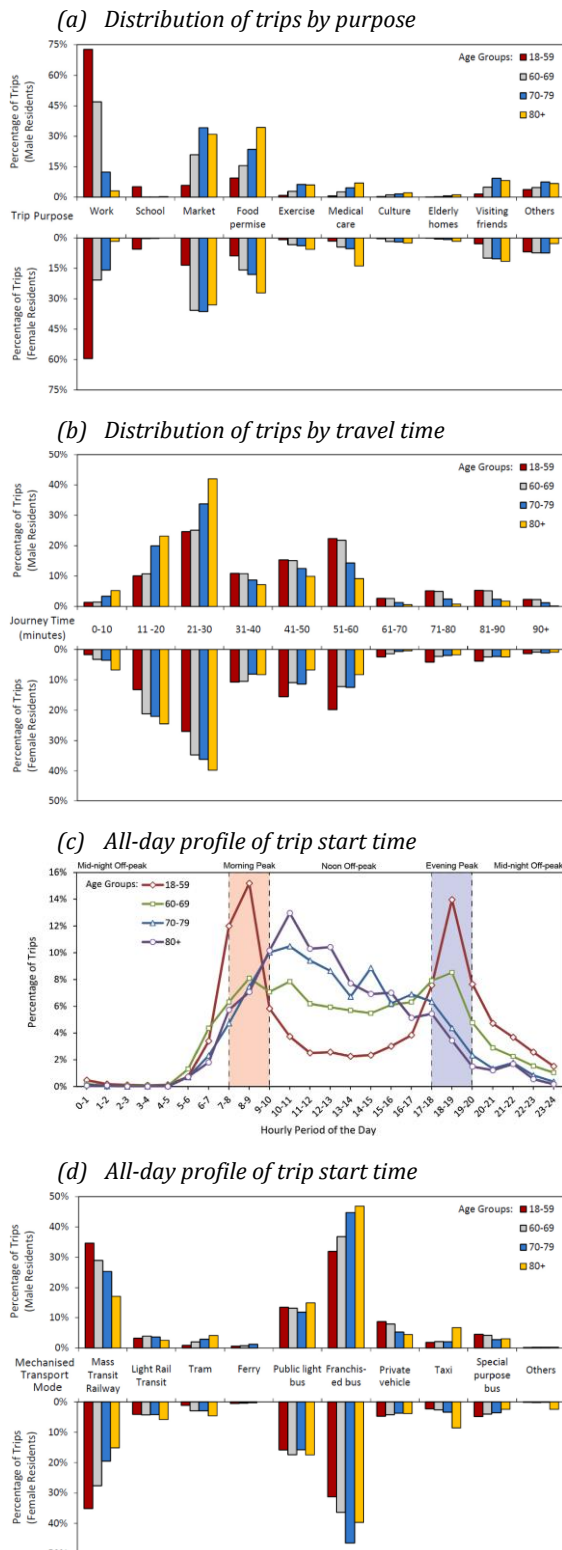
Figure 4-3 (d) presents the mode choice of the different age chorts and gender for the Hong Kong area. The graph indicates, the shift of elderly from *MTR* (Hong Kong subway) towards *franchised bus* (Hong Kong line bus services). A few possible explanations for the shift are seen in shorter transfers between lines, more direct services by busses and shorter accesses and egress times due to more frequent stops on streets. In addition, the elderly enjoyed traveling more by tram due to cheaper travel fares, and by taxi due to higher accessibility. (Szeto, et al., 2017)

Public transportation is expected to have a permanent decrease in transport volume until 2050, while private motorization is still expected to further increase. This is due to following mechanism:

As a result, the specific costs per user of transport infrastructures and for the provision of transport services are increasing when settlements shrink. Especially in public transportation, due to existing fixed costs based on capacities of its services which cannot be adjusted continuously and eventually leading to cost delays. (Westphal, 2008)

At the same time, the population carrying the financial load is decreasing, with the result that the costs per capita increases disproportionately. The decline and aging of the population is accompanied by losses of public budgets, making public financed transport infrastructures and services increasingly difficult to maintain. (Westphal, 2008)

FIGURE 4-3 | TRAVEL BAHVIOUR OF ELDERLY – HONG KONG



(source: Szeto, et al., 2017)

4.4 TRANSPORT SYSTEM FACING AGING AND SHRINKAGE

Shrinkage also offers an opportunity to reduce traffic loads. The process of thinning out the settlement structure present a challenge especially for public transportation and combined mobility.

Thus, even the financial needs to maintain transport infrastructures challenges municipalities with rationalization and increasing efficiency in an enormous way. A further increase in costs will result if existing transport infrastructures and services must be extended and widened due to *dispersion* of settlement. (Westphal, 2008)

De-densification as chance – private motorization:

A decline in population in inner cities offer opportunities for improving the quality of life in heavily traffic-loaded areas. With respect to private motorization, the population decline can lead to a reduction of traffic loads in peak hours and a partial demolition of road facilities, as well as a better organization of parked vehicles. Due to a performance confirm bundling of private vehicles loads towards a minimal network can set the footing for quiet living in the city, especially if it goes hand in hand with measures to improve the residential environment on the secondary network. (Westphal, 2008)

However, shrinkage and de-densification can also lead to disadvantages for private motorization. The longer routes of the thinned and perforated city can lead to the fact that the release caused by the population decline is partially reloaded by traffic. Although with low population densities the absolute maintenance expenditure for the road traffic infrastructure decreases, however, the specific expenditure increases per person. (Westphal, 2008)

De-densification and demographic change as a challenge for public transportation:

As already mentioned, the expected decline in demand is particularly affecting public transportation. In addition, the decline in total demand in public transportation and the increasing flexibility of the working environment in terms of space and time can cause a possible reduction transport volume during peak hours and therefore lead to an under-utilization of public transportation even in inner cities. (Westphal, 2008)

4.5 DISCUSSION & CONCLUSION

Elementary contribution of this chapter was to specify the two influencers of the aging society and shrinking cities which impact the DTL-circle as external factors. Aim was to describe their influence towards the development of transport system, land use and travel behavior. While *shrinkage* affects the land use segment of the DTL-cycle, an *aging society* affects people and their choices.

Similar to Japan is Germany a forerunner when it comes to aging and after the countries unification also confronted with shrinking cities in the 'new' federal states. (Klingholz & Vogt, 2013)

The federal government of Germany understood ***shrinkage*** as a "*multidimensional process of dissolution or decay of urban structures*" and concluded, that a further ignorance and passivity would favor the processes of shrinking and decay which can cause cities to collapse because of the lack of balance between population, housing and transportation.

An uncoordinated shrinking lead to a de-densification of settlements. Compact structures first *perforated* before entered a *disperse* state. Consequences where that these urban structures jeopardize economic feasibility and basic public services such as the supply of electricity, water, food and transportation.

To cope with shrinkage, the federal state program *Urban Redevelopment East* (translated form german: *Stadumbau Ost*) was launched in 2002. Its aim was to increase the quality of life, housing and work in East German cities with the help of two measures:

- ***Dismantling*** of building fabric in mainly abandoned areas,
- ***Revaluation*** and attractiveness of remaining residential areas in shrinking cities, and thus has a housing focus.

Westphal (2008) results lead to the conclusion, that adequate densities for urban structures vary from different planning points of view. Technical infrastructure such as for traffic and transportation require more compact structures, where in contrast, a thinned out urban structure holds advantages for recreational areas. This opposing demands to urban environments holds a huge potential for smart solutions as well as the compact city concepts.

In summary of Table 4-2: a functional and economic viable urban technology requires lower population densities as the assurance of a reliable and appropriate transport system. In tendencies, but not in general, an adequate urban technology requires higher population densities than the social infrastructure. However, in areas of low densities is the quality of social infrastructure needing for the same if not even for a higher density than urban technology.

In total Westphal (2008) has shown, that a certain standard of infrastructural quality is neither financially nor economically viable when an uncoordinated shrinkage takes place.

All of which has been observed and identified in the case of east Germany. However, this or a similar study in for the shrinking cities of Japan has not been found. Nevertheless, similar impacts of shrinkage are encountered in Miyagi prefecture. A similar study as of Westphal (2008) for the Japanese context is of interest and hereby recommended.

This chapter has shown, that aging and shrinkage occur parallel and are reinforcing each other. It also showed, that the solution against shrinkage and immobility of elderly is the same as for growing cities: a coordinated planning towards *compact cities* with an adequate minimum population density.

An adequate population density is of major importance for the economic feasibility and stability of settlements. It is of need for social integration and connection, as well as of importance for basic social needs such as high-quality transportation.

In transportation, population density is used to justify the economic feasibility of transport modes and their services. In urbanism, it demands and relates to the spatial structure and *spatial density*. Its effects *Building Intensity (FSI)*, *Coverage (GSI)* and *Spaciousness (OSR)* of buildings which shall be home to a given or aimed number of cities. Spatial density thus relates to a variety of housing typologies, which vary in FSI, GSI and OSR. (Berghauser Pont & Haupt, 2010)

Having the DTL-cycle in mind, a change in housing typologies, also changes distances between activities and therefore human behavior. With a change in distances, certain transport modes are more suitable than others which in result impacts mode choice and transportation.

TABLE 4-2 | MINIMUM POPULATION DENSITIES FOR INFRASTRUCTURAL EFFICIENCY

Typology	Density [Inh./km ²]			Infrastructure	Functionality	Economic efficiency
	Transport	Social Infrastructure	Housing demand			
Medium rise block	14.000 – 26.000	11.000 – 21.000	13.000 – 44.000	9.000 – 27.000	10.000 – 31.000	8.000 – 25.000
High rise compact strip	14.000 – 33.000	10.000 – 21.000	19.000 – 33.000	10.000 – 20.000	11.000 – 23.000	9.000 – 27.000
Medium rise compact strip	14.000 – 23.000	10.000 – 14.000	15.000 – 25.000	8.000 – 16.000	8.000 – 16.000	7.000 – 18.000
Multi-family house	6.000 – 19.000	11.000 – 14.000	13.000 – 21.000	6.000 – 13.000	-	5.000 – 11.000
Single-family house	2.000 – 8.000	6.000 – 7.000	8.000 – 12.000	> 6.000	3.000 – 8.000	3.000 – 7.000

(source: own illustration, based on Westphal, 2008)

PART FOUR

5 SCENARIO ANALYSIS

This chapter is dedicated to the scenario analysis the evaluation of their outcome.

Aim of this chapter is to identify “*what actions must be undertaken in order to reach a certain goal*”. (Geurs & van Wee, 2004) Within this thesis, that goal is the design of sustainable transport system for compact city development in an aging and shrinking society.

The subchapters 5.1.1 is presenting a qualitative forecasting scenario of the prefectures trends of *demographic change* and *urbanization* on the given transport system. Its insights, together with the goals of sustainability are used to define and present a desirable future of the prefectures transport system within a qualitative backcasting scenario in subchapter 5.1.2.

Both scenarios are evaluated towards their impact on the sustainability goals in subchapter 5.4 and 5.5. Its results are discussed in chapter 5.6 before a developments concept was derived and presented in subchapter 5.7. This chapter closes with a short discussion and conclusion in subchapter 5.8.

5.1 SCENARIOS

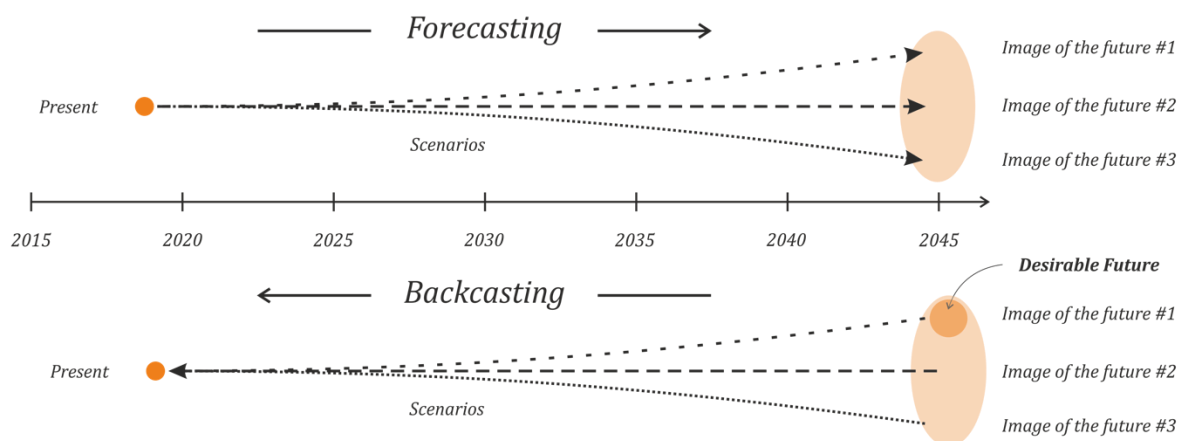
The two by Geurs & van Wee (2004) distinguished scenarios are **projective** and **prospective**. Both reveal possible futures and show a logical chain of events on how future events are linked.

As indicated in Figure 5-1, the *prospected* scenario's starting point is the current situation. It extrapolates the identified trends and results in a set of possible future images. A *prospected* scenario starting point is the desired future situation, which is usually described by a set of goals or targets. (Geurs & van Wee, 2004; Demos Helsinki, 2016)

The gained insights of the Chapters 1, 2 and 3 are included and serve as the foundation for the analysis.

Both scenarios are analyzed in a qualitative way within this chapter, based on expert judgement and funded on the insights of the chapters above.

FIGURE 5-1 | BACKCASTING



(Source: own illustration, based on Geurs & van Wee, 2004 and Demos Helsinki, 2016)

5.1.1 PROJECTIVE SCENARIO – FORECASTING

The here described *projective* scenario extrapolates the trends of *aging* and *shrinkage* of the prefecture's settlements until 2035 and 2045. It further describes their expected impact on the Transport system, land use and behavior of the prefecture.

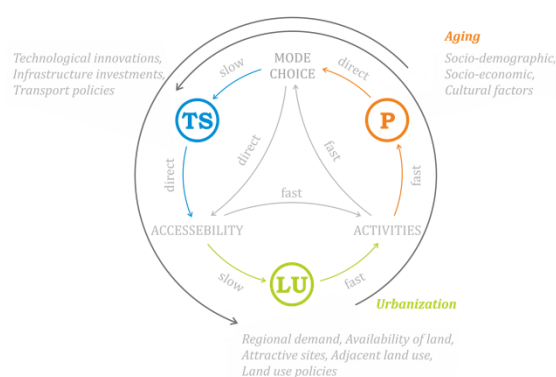
The here performed analysis is based on the insights gained from the literature review performed in Chapter 3 and 4 of this thesis and is therefore based on a qualitative performed expert judgement.

The following basic assumption are made to frame the development of the *projective* scenario (see Figure 5-2):

- *No or little guidance via transport and/or land-use policies are established.*
- *Technological advantages as of electric motorization and regenerative fuels as energy source are slightly considered.*
- *Economic situation of the Miyagi prefecture has been considered as stable, without major increase or decline of economic growth.*
- *Ecologic developments within the Miyagi prefecture (and the entire world) are not included. However, transportation shall, independently of its environment, not harm ecologic systems.*
- *Socially, the projected decrease in population as well as the societies enclosure to foreign ethnicities is based on the predictions of the 'National Institute of Population and Social security Research'*

The expected impacts on the prefecture's further development due to depopulation and aging are projected in the following subchapters.

FIGURE 5-2 | URBANIZATION AND AGING –
WITHOUT POLICIES



(source: own illustration and adaptation, based on Litman, 2002; Litman, 2016; Westphal, 2008; Rodrigue, et al., 2009 and Chorus, 2012)

5.1.2 PROSPECTIVE SCENARIO – BACKCASTING

The starting point of the here described *prospective* scenario is the desirable future situation of the prefectures sustainable transport system, which shall be achieved between 2035 and 2045.

Targeted is a private motorization of *150 Veh./1,000 Inh.* including car-sharing and taxi services, as aimed for by the German Environment Agency (*Umweltbundesamt – BAU*) (2017), as well as a minimum population density within the build environment, of about *8,000 Inh./km²*, as derived by Westphal (2008), MLIT (2011) and BAU (2017).

The prospective scenario builds up on the before performed forecasting scenario and takes its structure and outcome as foundation.

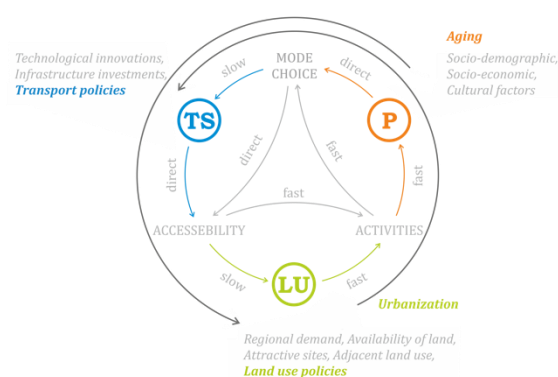
This scenario is based on the same methodology as the forecasting scenario where insights gained from Chapter 3 and 4 are used in a qualitative performed expert judgement.

The basic assumptions which are applied to the *projective* scenario also apply for the *prospective* scenario. However, one of them experienced a change:

- *Transport and Land-Use policies support modal diversity and compact city developments (see Figure 5-3).*

The expected further development of the Miyagi prefecture facing depopulation and aging is prospected in the following subchapters.

FIGURE 5-3 | URBANIZATION AND AGING –
WITH POLICIES



(source: own illustration and adaptation, based on Litman, 2002; Litman, 2016; Westphal, 2008; Rodrigue, et al., 2009 and Chorus, 2012)

5.2 FORECASTING

5.2.1 TRIP PURPOSE (P)

and travel destinations are expected to change due to the societies aging. Mandatory trips, such as to work or school will decline, due to a decreasing number of students and professionals. Optional trips, such as cultural or social trips, are expected to slightly rise due to an increased portion of retired people.

However, the overall *number of trips* is expected to shrink due to the general population decline (see Appendix 06 to Appendix 10, p. IX)

Private motorization, or *car ownership*, is expected to further increase as long as the individual cost for mobility will not majorly change. As a consequence, the ridership of public transportation is expected to decrease in volume. (Litman, 2002; Westphal, 2008)

An increase in car ownership is connected to urban sprawl which as a consequence leads to an increase in *Travel time*. Reaching daily, periodic or episodic destination will therefore require more time in traffic and transport.

due to aging, *trip start times* will slightly change and result in a spread and declined morning-peak as well as additional trips spread over the day in off-peak hours.

A further growing private motorization will further influence the *modal split*:

- **Private motorization** is expected to rise until 2035. Main reason therefore is the expected increase in car ownership. Reasons for an increase in car ownership (and usage) is seen in the growth of optional trips for leisure, insufficient coverage by public transportation and the de-densified urban structures. The later causes longer travel distances and times which excludes walking, cycling and public transportation as suitable options.
- **Public transportation** is expected to face a further decline in demand which is mainly due to the increase in private motorization. Also, the decline of students will have negative consequences for public transportation, since this age group uses busses and railways above average.
- **Active modes, pedestrians and cyclist, are projected to decline further.** Main reasons therefore are seen in the enlargement of distances due to suburbanization and the societies aging. Elderly commonly walk of cycle short distances, which is in contrary to students, who more than others commute by active modes. Also, an increase of car ownership will reduce the demand to walk or cycle.

5.2.2 TRANSPORT SYSTEM (TS)

Route choice is assumed to change. Based on a decreasing population, certain facilities for daily use might not stay viable when other facilities of larger settlements can easily be reached via car.

Due to a reducing number of inhabitants and working population, *link loads* are assumed to reduce and to become distributed over the day more equally.

Which also influences *travel time, speed* in a more positive way. Traffic and transportation might go smoother and congestion on the roads reduce simply by the decline in population and a smoother distribution over the day. *Travel cost* however are expected to rise, due to the lack of adequate demand in public transportation and infrastructural overcapacities of the road network. Some public transport service will face discontinuation due to the rising costs and reduction of demand.

Technological innovations, Infrastructure investments and Transport policies are further car oriented and will mainly take place in road bound traffic and transportation. New technologies to replace propulsion engines and reduction on fossil fuel demand are assumed to find their way on the Miyagi roads.

5.2.3 LAND USE (LU)

Sendai will maintain its status as economic centre of the Miyagi Prefecture and Tōhoku Region. The capital therefore will *attract* more of the younger working generation of the prefecture and regions countryside. Nevertheless, predictions indicate, that the number of inhabitants will stay more or less equal with an increase of elderly inhabitants.

Other settlements in the region will dramatically decrease in population size until 2045. Some of them until -50%. The largest part of inhabit at that time will be elderly of age 65 and above.

Other settlements are assumed to decrease in structural and social density. Resulting in an increase of abandoned sides and vacant lots in urban areas. Abandoned sides are further used as car parks, and less for living. Without adequate land use policies, it is expected that most settlements in the Miyagi prefecture first perforate before disperse urban structures develop.

5.2.4 AUTOMOBILE DEPENDENCY CIRCLE

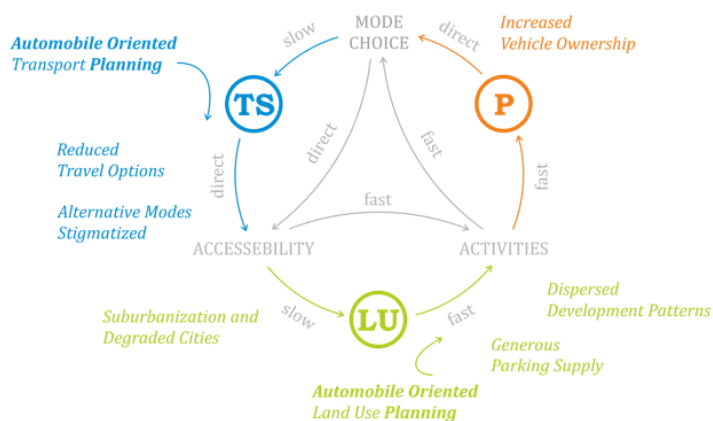
The projective scenario is consistent with the dominant trends which took place in the transport and land use development for the last decades. Rodrigue, et al. (2009) describes this “*evolution of urban mobility*” as follows:

- *The increasing private car ownership slowly affected land use development patterns.*
- *Developers were attracted to green field areas located between the suburban rail axes, and the public was attracted to these single-use [mainly low-dense] zones, thus avoiding many inconveniences associated with the city, mainly pollution, crowding and lack of space.*
- *Transit companies ran into financial difficulties and eventually [...] became subsidized, publicly owned enterprises.*
- *As time went on, commercial activities also began to suburbanize. Within a short time, the automobile was the dominant mode of transport. It has reduced the friction of distance considerably which has led to urban sprawl.*

Litman (2002) describes this development as a “*self-reinforcing cycle of increased automobile travel*”, since the sprawl increases the need for private motorization (see Figure 5-4).

An increased private motorization eventually causes decreases in density of the build-up environment. At the same time does un-coordinated shrinking (de-densification) lead to a decrease in population density, and thus to inefficient, expansive and incomplete public transportation, which as a result supports an increase of private motorization. (Litman, 2002; Victoria Transport Policy Institute, 2016)

FIGURE 5-4 | AUTOMOBILE DEPENDENCY CIRCLE



(source: own illustration and adaptation, based on Litman, 2002; Westphal, 2008; Rodrigue, et al., 2009; Chorus, 2012 and Victoria Transport Policy Institute, 2016)

5.3 BACKCASTING

5.3.1 TRIP PURPOSE (P)

The forecasted population developments indicated a dramatic decline in the number of citizens and their demographic composition. Thus, traffic and transport demand decline as soon as population numbers shrink and people age.

As a matter of fact, *trip purposes, number of trips* as well as *travel times* and *trip start times* will not differ to the assumptions and insights as pointed out within the forecasting scenario.

The aim of the governmental policies is to fulfill the goals of sustainability as pointed out in Chapter 2 (p. 13). All of which require the balance of all available transport modes with the purpose to combine each transport modes advantages. Different from the forecasting scenario is the goal of a balanced transport system which shall be realized by the prefectures land use and transport policies which aim to dramatically increase mobility costs for private motorization with the aim to reduce car ownership and co-finance collective transport modes. Public transportation and active modes (walking and cycling) are strongly supported to increase in service quality and prefectural coverage.

As a result, to the decreased motorization rate the *modal split* will switch towards an increased usage of walking, cycling and public transportation.

- **Private motorization** is expected to decline until 2035. Main reason therefore is a strived pricing policy for private motorization of the prefectural government.
- **Public transportation** is expected to face a high increase in demand. This increase is mainly due to the decline in private motorization and the governmental program to densified urban structures around bus stops and stations. The later results in more urban activities around public transport access points, shorter distances and thus shorter travel times. In combination with a better walk and bike ways, the densification will promote walking and cycling for short distances towards activities and public transportation for longer distances as suitable options for all age groups.
- **Active modes, pedestrians and cyclist, are strived to increase again.** Main reasons therefore are seen in the shorter distances to activities in a densified settlement as well as the strived reduction in private motorization. Elderly commonly travel shorter distances by walking of cycling, but demand a high level of traffic and transport safety. This results in a barrier-free and prioritized design of walk and cycle ways. An increase of adequate walk and cycle ways thus increases the demand for walking and cycling within all age groups.

5.3.2 TRANSPORT SYSTEM (TS)

With respect to private motorization, the decline in car ownership lead to a reduction of traffic loads in peak hours and a to a reduction or de-construction of oversized roads. Performance confirm bundling of car mobility towards a minimal network can set the footing for quiet living in the city, especially if it goes hand in hand with measures to improve the residential environment on the secondary network.

Rail based public transportation is aimed to become the backbone of the transport system of the Miyagi prefecture with settlements shrinking and densifying around stops and stations of collective transport modes. Although the decline in total demand for transportation and the increasing flexibility of the working environment can make it possible to reduce transport volumes during peak hours. However, the usage of public transportation is estimated to increase with the decline of car usage (see Appendix 13, p. XVII).

Policies toward transportation supports the development of sustainable transportation with the following four criteria:

- **Adequate establishment of walk and cycle ways for high quality public spaces**
- **Better connectivity for short distances and continuously designed walk and cycle ways, providing access to activities and public transportation**
- **Increased quality of public transportation to allow spontaneous, barrier free trips to other settlements and attractions.**
- **Decommission of automobile-oriented street design in order to decline the usage of private motorized vehicles and increase the quality of the public space.**

5.3.3 LAND USE (LU)

Shrinkage offers an opportunity to reduce traffic loads and de-densified settlements present a challenge for combined transportation to operate feasible within the *disperse* settlement.

Policies towards land use support the development of urban structures with the following three criteria:

- **Adequate density for high quality public transportation**
- **Functional mix for sufficed social interconnection, support of basic social services**
- **Compact city structures to allow short walking and cycling distances towards activities which is within a coverage area of a public transport access point (i.e. railway station or bus stop) for adequate interconnection.**

5.3.4 BALANCED TRANSPORTATION CIRCLE

As major factor pointed out by this scenario is to reach the following aims...:

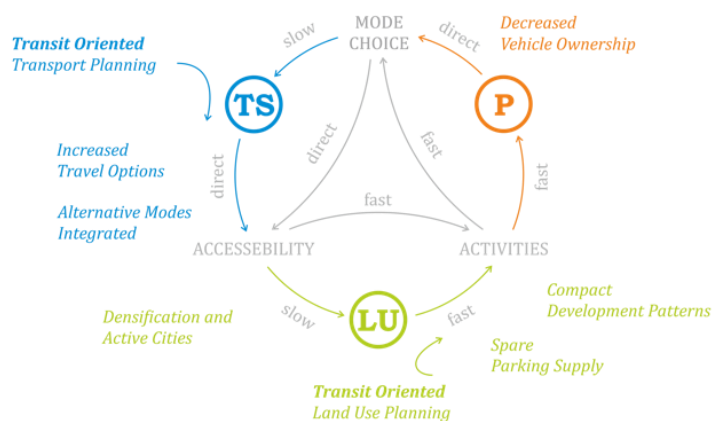
- a) ...to dramatically **reduce private motorization** and
- b) ...to **support adequate population densities** around public transport access points.

Including both objectives towards a *self-reinforcing cycle of sustainable transportation*, the following development can take place (see Figure 5-5):

- *The encouraged decrease in automobile ownership slowly effects land use development patterns. In addition, this land use effect can be supported by adequate land-use development strategies.*
- *Developers would be attracted to access points of public transportation and the public would be attracted to these areas due to fast and convenient connections.*
- *However, developers are challenged to include noise protection, space and standards for eco-friendly housing into their developments, which shall provide a minimum density. The public transport system on the other hand must provide a frequent, safe, clean, comfortable and reliable service and the access to it shall be convenient for walking and cycling which avoids crowding.*

- *Public transport companies can increase their patronage and therefore decrease their demand on subsidies.*
- *As time goes on, commercial activities also begin to re-urbanize, which shall be promoted by adequate land-use planning.*
- *Within a short time, a transport system based on active modes and public transportation can become the backbone of transportation. Adequate densities and functional mix can reduce the friction of distance and thus lead to compact and active settlements.*

FIGURE 5-5 | BALANCED TRANSPORTATION CIRCLE



(source: own illustration and adaptation, based on Litman, 2002; Westphal, 2008; Rodrigue, et al., 2009; Chorus, 2012 and Victoria Transport Policy Institute, 2016)

5.4 PROJECTIVE SCENARIO (FORECASTING) – IMPACT TOWARDS SUSTAINABILITY GOALS

With the aim to fulfill all set sustainability goals, the following goal has been established:

Economical:

- *Transport system efficiency is expected to increase, due to population decline, increase of elderly who are unwilling to drive and a more even distribution of trips over the day. As a result, travel speed of private vehicles increases and traffic congestion declines.*
- *However, the transport system is expected to further increase into an automobile dominant transport system and will therefore prevent a well-integrated combined mobility.*
- *Accessibility will more and more be linked to vehicle ownership and as result reduces the access to transport and activities for people which are not able to drive due to variety of reasons, such as age, physical disabilities or fear for driving.*
- *Automobile dominant transport systems increase many societal and operational costs: higher vehicle expenses, reduced travel choices, increased communal and infrastructural cost for roads and parking facilities, damages due to accidents and a variety of negative environmental impacts.*
- *Economic and business developments can face a reduction in economic productivity and growth, since access is reduced to people who have access to a private vehicle.*

Environmental:

- *With a development of the Miyagi transport system towards a further automobile dominant transport system the emissions of air pollutants will not decrease. However, modern technologies, which are currently in development, might tackle pollution and can lead to cleaner vehicles and air.*
- *The amount of resources used for transport per capita will not change or even increase. This due to a higher degree of motorization as well as the amount of energy which is needed to power a vehicle.*
- *Private motorization and its related infrastructure require a lot of space, and therefore consume valuable soil for farmlands and water protection as well as other transport modes or urban development.*

Social:

- *With the development of an automobile dominant transport system more and more people of Miyagi will face, that their travel demands are not be covered by other modes. The mono-modal system lacks on modal diversity resulting in a variety of destinations which cannot be reached by people with disabilities or low income or the unwillingness to own or drive a car.*
- *Casualties in road traffic will still be high or even increase, simply to a high exposure to private vehicles on the narrow prefectural roads. However, an increase in road safety can be seen by the implementation of better driver support systems currently in development which can take over and stop the vehicles in case of an approaching accident.*
- *Public health is expected to decrease, mainly expected in the suburbs of Sendai, due to the lack of physical activity when using the private automobile for everyday trips.*
- *Vehicle infrastructure, when dominating the buildup environment, breaks communal quarters apart and neglects the communal cohesion of paths and settlements when not addressed.*
- *Walk ways and squares, which describe the quality of stay, help to encounter people and shape communities and societies. With the lack of walking and cycling, people interact with each other less resulting in a disappearance of local culture and societal segregation.*

5.5 PROSPECTIVE SCENARIO (BACKCASTING) – IMPACT TOWARDS SUSTAINABILITY GOALS

With the aim to fulfill all set sustainability goals, the following goal has been established:

Economical:

- *Transport system efficiency is expected to increase, due to prospected decline in private motorization, support of all transport modes and a more even distribution of trips over the day. As a result, travel speed of every transport mode increases and congestion on roads as well as crowding in collective transportation declines.*
- *The transport system is expected to further transform into a balanced modal system and therefore increase multi-modality and establish a well-integrated combined mobility in the prefecture.*
- *Accessibility to all kinds of activities is provided via all identified modes of transportation and available for everyone. Personal preferences and capabilities decide over the mode of choice and people with physical disabilities or fear for driving are not left behind.*
- *A balanced transport system decreases societal and operational costs: travel choices increase leading to communal and infrastructural cost for roads and parking facilities to decrease. As a result, the number of accidents and a variety of negative environmental impacts are lowered.*
- *Economic and business developments can face an increase in economic productivity and growth, since access to jobs and production is provided to every one of every social class.*

Environmental:

- *With a development of the Miyagi transport system towards a balanced transport system, emissions of air pollutants will decrease simply by the efficient combination of collective and private transport modes. In addition, assumed modern technologies tackling air pollution can further lead to cleaner vehicles and air.*
- *The amount of resources used for transportation per capita will decline even when ridership numbers increase. This is expected to scope effects influencing the systems efficiency.*
- *The balance of transport modes gives less space to private motorization and more room to collective and non-motorized modes. With the transportation towards more efficient modes, space and settlements can be reduced which reduces impervious surface areas.*

Social:

- *A balanced transport system provides a diverse range of modes and the development of diverse activities around them. Further, this results in a variety of destinations which are reachable by people with disabilities, low income or the unwillingness to own or drive a motorized vehicle.*
- *A reduction of private motorization directly decreases road traffic casualties due to a lack of exposure. An increase in road safety can be seen by the implementation of better driver support systems currently in development which can take over and stop the vehicles in case of an approaching accident.*
- *Public health is expected to increase, due to an increase of walking and cycling as physical activity for everyday trips.*
- *A transport infrastructure, when designed equal for all transport modes, supports the buildup environment and connects communal quarters and builds, leading to communal cohesion of paths and settlements.*
- *Walk ways and squares, which define the quality of stay of an area, help to encounter people and shape communities and societies. With an increase of good walking and cycling infrastructure, people interact with each other more which result in a manifestation and further development of local culture and societal integration.*

5.6 RESULTS

The **projective** scenario illustrated how the current trends and an unguided development could lead to an automobile dominant transport system.

The **prospective** scenario on the other hand illustrated the ideal case of Miyagi's transport system which fulfills the environmental integration and socially connectivity of each settlements and its citizens of all age.

The comparison between both scenarios and their relation to the goals of sustainability highlights their discrepancies.

Based on the scenario's comparison, the following discrepancies can be indicated:

- A) *Automobile dominance does not include all transport participants.*
- B) *Private motorization leads to urban sprawl and both towards a high demand of resources.*
- C) *Zonal distribution and functional separation lead to high traffic and transportation needs as well as social segregation.*

As a first intermediate result, the following list summarizes the *fields-of-action* for the development of a balanced and sustainable transport system for the Miyagi prefecture: (Litman, 2002; BAU, 2017)

Land Use planning shall include the following action points into a **smart shrinkage** development program:

- a) *Increase in density*
- b) *Increase in functional mix*
- c) *Decrease in spatial occupation of communities*
- d) *Development around PT access points*

Transport planning shall focus on the following actions as part of the **Access-for-All** development program:

- Individual Transportation
- e) *Reduction of automobile infrastructure*
 - f) *Sustainable street design*
 - g) *Implementation of walk ways*
 - h) *Implementation of bike ways*

- Collective Transportation
- i) *Better infrastructure*
 - j) *Direct and fast network*
 - k) *Attractive access points*
 - l) *Increase in Service*

- Technological Innovation
- m) *Implementing new and alternative technologies.*

The following subchapter elaborates certain elements which are required for the prefecture's sustainable development:

5.6.1 ELEMENTS FOR SUSTAINABLE TRANSPORT TRANSFORMATION

With the aim to fulfill all set sustainability goals, the following elements has to be established: (United Nations, 2016; BAU, 2017; ITDP, 2017)

Economical:

- **Capacity** of vehicles is provided in accordance to comfort goals of users and the optimal utilization of resources.
- **Velocity** of vehicles is related adjusted to type and function of a road.
- **Travel speed.** Velocity and street design for access roads, within urban and rural areas, is maximum 30 km/h.
- **Car- and bike-sharing** are covering the Miyagi prefecture.
- **Private vehicles** have a way lower status in urban and rural traffic.
- **Destinations** can be reached flexible, comfortable, time- and cost-saving by walking, cycling or public transportation.
- **In urban environments, fewer private vehicles** operate as of the modal split of 2002. All of which are more efficient. Less space is dedicated to traffic and all vehicles operate with regenerative energy, either electricity or hydrogen.
- **Backbone of the prefecture and settlements is Public Transportation** which combines the advantages of both, rail and road bound transportation. The service is reliable, quick and safe, also by unforeseen interruptions.
- **A further intensified parking management** make it expensive to park in dense areas. **Space for living** is prioritized over space for **parking**.
- **The separation** effect of traffic and transport corridors is reduced or repealed.
- **Resources** needed for urban transport infrastructures, modes and ways (including demand for vehicles) is minimized.
- **Creation and development costs** of mobility for municipalities are secured by the government.

Environmental:

- **Renewable fuels and energies** run urban and rural traffic and transportation (nearly) emission free
- **Within inner-cities just motorized vehicles operate which run by electricity.** The entire Public transportation is operating with electricity.
- **Electricity is won from renewable energy sources.**
- **All quality standards** against air pollutants are **meet and exceeded.**
- **Noise exposure, caused by technical sources are prevented**
- **Recreational areas** close to living areas are **preserved** and for noise increase **protected**

5.6.2 INTERCONNECTION OF GLOBAL OBJECTIVES

Social:

- **Daily destinations** can be reached by everyone without an automobile. Ideally via short distances by walking and cycling.
- **Goods and Services** available by the frequency of demand are easy to reach: daily by walking, in periodic by cycling and public transportation, episodic by public transportation or (shared) automobile.
- Each transport mode can be accessed **barrier free**.
- **Mobility for everyone** is available and possible without the help of others or strangers.
- The transport system facilitates an **age-appropriate mobility** without an own vehicle, services of assistance or technical mobility support.
- The perceived subjective safety and security in traffic and transportation is high.
- **No traffic deaths, or heavily injured people** based on sustainable transport infrastructure.
- **Quick help** is guaranteed in emergencies due to short distances.
- **Residential use in inner-city** quarters is strengthened and **public areas for encounters** and interactions are provided.
- **Noise and Emission free businesses** are preserved or re-integrated in urban areas. **Noisy** businesses shall be avoided in mix-used areas or placed in business parks as alternative.
- **Inner-city areas will become structural densified**. This is due to the re-usage of abandoned sites, usage of backyards or unnecessary parking lots.
- Abandoned sites, are re-used and re-activated. Mainly by construction forms which allow an **attractive and healthy living with high quality** despite densification.
- Living is **adjusted towards the needs of old and young** and flexile organized.
- Utility services for daily requirements, as well as cultural facilities and societal venues are diverse and cover the needs of different age groups and user groups.
- The advantages of enclosed constructions are used to build silent backyards in active quarters
- Access to affordable housing has been made easier and a spatial separation between poor and rich is prevented.
- Meeting zones, where each transport modes are equal shape the urban and rural scape.
- Qualities of stay in public space is high due to public seating and low noise pollutions.
- Areas to encounter and meet, regenerate and communicate are diverse.

The scenarios and their interconnection towards the sustainability objectives point out, that most of the identified elements for a sustainable development of the prefectural transport system refers to a better build-up environment for all transport modes but automobile infrastructure. All of which are directly linked and referring to an increase of the *Universal Access* towards transport modes, and areas of attraction.

The quality of each infrastructure and network – either for motorized vehicles or collective transpiration – influences the modes efficiency and direct safety.

Just when the network is covering all activities in a safe, direct way a switch towards alternative modes will happen and increase the need for green alternatives (see Figure 5-6).

As conclusion: each transport mode is as good as its physical infrastructure and network which is defined by the objectives of **Universal Access (UA)**.

Its **efficiency (EF)** and **safety (SA)** of the system depends on the service quality of the buildup infrastructure and coverage of the network.

In the end, the qualities of the three of them combined makes it possible to provide an environmentally friendly **green mobility (GM)**.

FIGURE 5-6 | INTERRELATION OF GLOBAL OBJECTIVES



(source: own illustration based of SuM4All, 2017)

5.7 DEVELOPMENT CONCEPT

The vision of a prefectural transport system able to face de-population shall be described with the following overall concept. It describes how inhabitants of all age can be mobile in a sustainable way by a *balanced* transport development plan, described by the following bullets points:

A) Compact development

Aim is the redevelopment of the given urban settlements towards an adequate dense and functional mixed urban structure, which supports the people's independency of private vehicles:

- **Compact settlements:**
Abandoned sites and areas currently used as parking lots shall be re-developed. These areas hold the potential for a re-densification and increased functional mix of quarters.

*Major target is to increase population density within the buildup environment. With reference to Westphal and the MLIT, adequate population density of at least **8,000 Inh./km²** and related new housing typologies is aimed for.*
- **Walking, cycling and collective transportation:**
Main artery roads shall be redesigned to accommodate walk and bike ways as well as separate lanes for collective transportation. Parking spots and garages for bicycles shall be provided close to stops and stations. Collective transport coverage and service shall be intensified.
- **Decommissioning of the automobile friendly road network:**
Roads are reduced in size towards adequate traffic flows. Additional space, which is gained by the decommission, is used for wider pedestrian paths, bike paths or separate lanes for collective transportation. Access roads are prioritized for walking and cycling.

*Major target is to decrease private motorization within the prefecture to at least **150 Veh./1,000 Inh.***
- **City of short destinations:**
Basic services (i.e. groceries, public transport access) shall at maximum be just 10 min. walking away.
- **Quick in and out:**
Settlements are the core of each municipality. Each settlement therefore, shall be connected via prefectural bike paths and bus services which connect each core with each other.

B) Green Environment

The given green (flora) and blue (water) environment shall be preserved and canals re-naturalized. Areas which will become free due to decommission are committed towards the creation of new green and blue environments in order to adapt towards heat stress and water flood mitigation:

- **Green and Blue areas**
Given once are preserved and new once are created on former urban areas. Both areas preserve biodiversity and conditions the local climate. The new space shall back hold water after excessive rainfall and otherwise offer recreation for citizens.
- **High Quality Living Environment**
living and work increases in livability due to high quality green areas, green squares and streets as well as passages and other public areas.
- **Health**
Green and blue areas promote outdoor activities and therefore support the health of the people.
- **Green instead of concrete**
Green and water areas on rooftops, along facades and backyards increase the attraction of the build environment and create a pleasant chill in summer times and delays rain water during heavy rainfall.

These development steps include the elements pointed out in subchapter 5.6.1 (p. 41). After the elaboration of the backcasting scenario, these concepts have been identified by working backwards to derive needed structural changes in the build environment as well as the policies which are required to reach that future.

5.8 DISCUSSION & CONCLUSION

Major contribution of this chapter is the performed scenario analysis and the evaluation of their outcome.

The *projective* scenario shows that the current trends of aging and shrinkage in an unguided development could lead to automobile dominant transport system which further incorporates urban sprawl and threatens the quality of a municipalities core as the economic and cultural heart of each municipality.

The *prospective* scenario describes the desirable future transport system which is in accordance with the goals, objectives and targets of sustainable transportation. One mayor factor for attractive, efficient and balanced settlements is an adequate level of population density as well as jobs per settlement or quarter. The outcome shows that with regulative policies towards motorization and population densities a sustainable development can be initiated.

The comparison of both scenarios' pointes out the following three aspects:

- a) *Automobile dominance does not include all transport participants.*
- b) *Private motorization leads to urban sprawl and both towards a high demand of resources.*
- c) *Zonal distribution and functional separation leads to high traffic and transportation needs as well as social segregation.*

Multiple field-of-actions are identified in order to overcome the identified discrepancies. As a result, land use and transport planning shall include these into a *smart shrinkage* and access-for-all development plans.

Major insight from the identified field-of-actions is the high importance of quality and coverage of the build transport infrastructure, defined and summarized by the objective group of **universal access**. **Efficiency** and **safety** highly depend on the quality and coverage of a mode's infrastructure. The combination of the three objective groups – with *universal access* as foundation – makes environmentally friendly **green mobility** possible.

The identified fields-of-actions are further related to the following three *design-fields*:

- 1) **Street design**, which is in favor for active modes and road based public transportation.
- 2) **Public transportation design**, which build up the back bone of an areas transport network and service.
- 3) **Compact city design**, which promote adequate dense populations and housing types which support a distribution of different functions and short destination.

A further aim of this section was to quantify certain projected and prospected developments. In order to do so three calculations were performed with a short *back-of-the-envelope* approach.

At first, the *prospected* reduction of the prefecture's motorization degree towards *150 Veh./1000 Inh.* and its impact on modal split was conducted. The *second*, the impact of the *projected* decrease in population towards population density was showed. At *third*, the potential areal occupancy was calculated, based on the *prospected* minimum density of *8.000 Inh./km²* for all identified settlements in Miyagi.

The entire section on quantification is provided in Appendix 13 (p. XVII) and Appendix 14 (p. XVIII). The calculations rely on the available data from the Sendai MEA only, since modal split data on the other municipalities were not available. The results should therefore be used with caution towards other municipalities within the Miyagi prefecture.

The *prospected* impact on the MEA's modal split would **nearly double** the usage of all other transport modes. However, the rapid decline in population would result in an increased number of trips which will by a maximum of **+56%**.

A *projected* uncoordinated shrinkage could lead to a **-58.5%** in population density within the buildup area and therefore directly impact the economic feasibility and reliability of classic public transport modes.

Assuming a stable *prospected* minimum population density a buildup environment of the size of **247.46 km²** can be decommissioned, and become dedicated to re-naturalization. An area as equal to the size of the municipality of Amsterdam.

Relevant measurements into these directions are further elaborated in the upcoming chapter.

6 IMPLEMENTATION REQUIREMENTS

The Ideal case is of no use if it is not pointed out how to make it real.

This chapter elaborates on requirements and related principles at first before introducing concepts and their related measurements on how to achieve sustainable transportation designs for a regional transport system which face *demographic change*, *shrinkage* and *climate change*.

Requirements for the development of the before described ideal case are derived from the difference between the given transport system and external factors. The first subchapter 6.1 will further elaborate on them.

These requirements relate to eight **principles** for the sustainable development of transportation and land use as provided by the *Institute for Transportation and Development Policy* (ITDP, 2017) and discussed in subchapter 6.2. Five of which are directly related to transport development and three towards Land Use planning.

Out of the before introduced principles, four **design concepts** are developed in subchapters 6.2.1 to 6.2.4. Many of the given advises are not new. However, these concepts, which are generally known, are still of relevance since they are not well implemented yet. On the recognition of concepts, just highly effective ones where noted and which can be realized within the upcoming 20 to 30 years.

Multiple **measurements** are connected towards each design concept. Duplications are avoided, even as measurements can be connected to more than just one concept. Each of the concepts and measurements are not standing on its own and are interconnected with each other. One measurement on its own has very low impact. All of them therefore must be seen in the broader context as their synergies unfold in their interconnection.

The here presented concepts and measurements focus on sustainable transport design under the impact of aging and shrinking. The concepts indicate the tight (and often underestimated) bond between transport and land use planning for livable and sustainable settlements. (Morimoto, 2012; Murayama, 2016)

However, for an overall concept for future developments more questions need to be solved. Some of which are related to resilience, climate adaptation, energy supplies and resource protection. Those topics are not further elaborated on within this thesis. Nevertheless, the here presented concepts can be seen as first steps for further, more detailed concept but as foundation for everything upcoming.

6.1 IDENTIFIED REQUIREMENTS

In order to elaborate concepts and related measurements for the development of a sustainable transport system design, the identified ideal scenario (Chapter 5.1.2, p. 34) was compared to the given transport system of the prefecture (Chapter 3, p. 19) and external influencers (Chapter 4, p. 27) The identified *deficits* between the given and the ideal cases are the design requirements for each case study.

$$\text{Step 3} + \text{Step 4} + \text{Step 6} = \text{Step 5}$$

$$\text{Step 6} = \text{Step 5} - (\text{Step 3} + \text{Step 4})$$

Sustainable Transport System design for the shrinking settlements and the aging society within Miyagi prefecture requires the following improvements:

1. **Better walking infrastructure and network**
2. **Better cycling infrastructure and network**
3. **Better connected quarters by walking, cycling network and public transportation for longer distances**
4. **Better infrastructure, coverage and service of public transportation**
5. **Reduced car-oriented street design and parking spot supply**
6. **Re-use of abandoned sites for inner cities or ground level parking lots for housing development of medium density**
7. **Better functional mix of living, leisure, recreation, retail, care and soft industries.**
8. **Spatial planning measures for land use development towards the compact city.**

6.2 GENERAL DESIGN PRINCIPLES

Within this section, emphasis is set on the **Compact Development (A)** of Miyagi's municipalities and therefore does not further elaborate on the implementation of the indicated **Green Environment (B)**.

The compact development follows a set of design principles which will be introduced first, Concepts for a sustainable, age friendly and compact redesign of the Miyagi prefecture is described in accordance towards those principles.

As an alternative towards *projective* planning paradigms the concept of *Transit Oriented Development (TOD)* closely integrates "urban forms and land uses [...] with efficient, low-impact, and people-oriented urban travel modes: walking, cycling, and transit." (ITDP, 2017)

The design principles derived and provided by the *Institute for Transportation and Development Policy (ITDP)* introduce measurements towards an efficient walking, cycling and public transport oriented urban structure. All of which shall ensure that the motorized populations of industrial economies overcome automobile dependency and that the new urban middle-classes of developing and emerging economies leap-frog into the age of advanced car-free (or low-car) lifestyles. (ITDP, 2017)

Five of the eight TOD principles, which are presented below, are directly or indirectly connected towards transport planning its connection towards the DTL-circle. They are marked with an '**TS**' for identification. The others are connected to Land Use planning and are indicated by a '**LU**'. All TOD principles, as short description and the identified connection towards the general DTL-circle is listed below:

1. **Increase ability to walk (TS)**
towards neighborhoods that promote walking
2. **Increase ability to cycle (TS)**
to prioritize non-motorized transport networks
3. **Increase connectivity (TS + LU)**
to create dense networks of paths and streets
4. **Increase Public Transportation (TS)**
towards high-quality services
5. **Support Transport Shift (TS + LU)**
by regulating parking and road usage
6. **Densify (LU)**
in order to match minimum requirements for public transportation
7. **Increase functional mix (LU)** to increase diversity, income and demographics of a settlement.
8. **Build compact settlements (LU)**
with short ways and short commutes with collective transportation

These principles and their related measurements are, however, practically and politically viable only when combined with each other. In their combination, they will lead to a rewarding and attractive alternative towards automobile-oriented developments. One on its own, will barely make an impact but the interaction and integration of them is expected to lead towards a sustainable and reliable way of life. (Litman, 2016; ITDP, 2017)

Within this thesis, each principle is tuned towards the specific Miyagi case. Main focus of each concept are the case related requirements which will be transformed into *practical* and *political* measurements for their realization.

Transport System (TS)

Shrinking cities, villages or urban quarters face the need to reduce their infrastructure and to maintain a basic service in public transport. Growing cities have to face how to handle the increasing demand on traffic and transport.

The following subchapters 6.2.1 to 6.2.3 presents transport related development concepts which face the aging society and urbanization. Its related measurements are related towards the local conditions of Miyagi but are of general importance as well.

Land Use (LU)

At the same time cities, villages or urban quarters face the need to maintain their social integration and to provide basic services for living, working, leisure and regeneration. Growing cities on the other hand face the challenge on how to provide short distances towards a large variety of those services.

The subchapter 6.2.4 present development concepts which are related to land use immersing the requirements for an aging society and urbanization. The measurements are oriented towards the local conditions of the specific case of Miyagi but are related towards general importance as well.

6.2.1 ACTIVE MODES (WALKING AND CYCLING)

Principles 1, 2 and 3

The share of walking and cycling within the Miyagi prefecture is high, compared in an international context. However, over time, from 1982 to 2002, the share of walking and cycling population shrank. (ITDP, 2017)

A clear concept for the implementation of such a network for cyclists and pedestrians is of importance for the livability of an area and, as Sze & Christensen (2017) pointed out, of important for the mobility of the elderly.

A tight network of paths and streets offer multiple routes to many destinations which by themselves are preferably to be enjoyable. (ITDP, 2017)

Research has shown that a block of about one hectare and a block face averaging about 100 meters (m) present the optimum trade-off for the development of denser networks mean more land devoted to rights of way and the capacity to accommodate larger development plots. (ITDP, 2017)

Concept

Within Miyagi, the priority of pedestrians and cyclist over private vehicles can be observed in the narrow, often well-connected access-streets of each community.

This established culture of narrow roads shall be strengthened by an adequate street design which manifests walking and cycling as priority. Active modes shall be supported and therefore increased in attraction. It requires a complete and dense network which provides short and direct connections towards activities and public transportation.

Important therefore is the build infrastructure of each path and its adjacent buildings which must be safe, attractive and comfortable to use. Attractive adjacent buildings, routes via green areas, lighting, barrier freedom, maintenance and safe street crossings are measurements of importance. In addition, cycling requires safe street conditions as well as secure cycle parking and storage.

In combination with higher frequencies, easier transfers and overall coverage of public transportation is any activity within range and therefore better connected.

Measurements

- *Develop and implement a prefectural design guideline for the development of homogeneous and safe walkways. The guideline shall implement a design standard for:*
 - (a) *Dedicated sidewalks protected from vehicular traffic by a curb (applicable to roads with high traffic flows such as national and prefectural roads).*

- (b) *Shared space for safe road sharing between pedestrians, cyclists, and private motorization and pedestrian-only zones and zones of reduced traffic (i.e. downtown Yokohama)*
- (c) *Safe crosswalks and driveways with priority towards walking and cycling.*
- (d) *People of age and/or with physical disabilities according to their requirements.*
- (e) *Guiding system for pedestrians and visitors towards public services and attractions.*
- *Develop and implement a prefectural design guideline for the development of homogeneous and safe bikeways. The guideline shall implement a design standard for:*
 - (a) *Dedicated bikeways protected from vehicular traffic by a curb or bike lanes in road space. (applicable to roads with high traffic flows such as national and prefectural roads).*
 - (b) *Cycling corridors with dedicated sidewalks as connectors between city quarters and rural settlements.*
 - (c) *Safe road crossing and driveways with continues design of walk and cycle ways.*
 - (d) *Bike racks in public space and bike garages in buildings as well as their interconnection towards bus stops and station.*
 - (e) *Guiding system for cyclist and visitors towards public services and attractions.*
- *Develop and implement a prefectural network development guideline for the development of a hierarchical structured network of walk and bike ways. The guideline shall implement a design standard for:*
 - (a) *A complete, safe, attractive and direct network of walk and bikeways covering the entire prefecture in order to provide an interconnected network to access any activity.*
 - (b) *Short and direct access routes toward activities as well as public transport access points.*
 - (c) *A strong and dense network of shared-roads and pedestrian only zones within urban core areas.*
 - (d) *A small average block sizes of no more than 1.0 ha shall be provided as contribution to provide walkable blocks.*

6.2.2 SHIFT

Principle 5

Historically, streets were conceived to satisfy external and internal demands for transportation, but not less important, they served as public space for citizens with multifunctional purposes. (ITDP, 2017; Colville-Andersen, 2012)

Currently, street space is mostly oriented towards the requirements for private motorized transportation. And due to the lack of public parking facilities alongside the streets, Japanese roads are mainly oriented towards processing traffic flow. (ITDP, 2017; Colville-Andersen, 2012)

The road network is well developed, with emphasis on national and prefectural roads. Those type of roads mostly function as connector and distributor roads within the prefectures network and are therefore designed for high traffic flows. Within community's prefectural roads function as a connector between districts but also as distributor and collector. The unnamed narrow side streets provide access to the neighborhoods. A road hierarchy therefore is visible but based on a demand respective adaptation of road segments. An overall hierarchy which considers the needs of active modes and public transportation is not established. (ITDP, 2017)

As a result, narrow side roads consequently are more oriented towards walking and cycling. Prefectural roads with multiple lanes on the other hand are capable to handle high traffic flows. (ITDP, 2017)

In the last decades Miyagi has seen a constant increase in car ownership and the demand for parking has increased with it. Due to the thinning of urban areas abounded sites increased and gave space for, an increased amount for parking lots, especially in inner-core areas of settlements, which also applies for Sendai.

Concept

Aim of the Miyagi transport concept is to switch from private vehicle-oriented transportation towards walking, cycling and public transportation.

Consequently, a gradual but proactive reduction and de-construction of roadways and parking space availability along settlements is needed to lead to a shift in transportation.

Figure 6-1 and Figure 6-2 indicate how street design can indicate *shift* and set priorities to modes in a Japanese context. These figures are based on the Dutch for sustainable street design. (Wegman & Aarts, 2006)

Many measurements to reach this aim are not new but most of the time established in an inconsequent way and therefore miss out on their positive impact towards active modes. One major tool to support modal shift is pricing. Car usage can be reduced via an increased pricing policy for roads and parking.

A person who has to pay a lot for driving and parking rather uses cheaper alternative modes than the private car.

The concept of infrastructure pricing can be adjusting further towards demand and distance-oriented pricing models. An increased amount of toll roads and tiered pricing based on road category and speed can be an economic measurement for car use reduction along connector roads and enforce environmental protection in accordance to the "polluter-pays" principle. Prices for parking can be combined with smart-city-developments and therefore designed demand oriented. Parking in general shall be expensive, but areas with a high demand for parking during peak hours shall even further increase in pricing (connected to *principle 4*).

Certain areas of settlements, such as core areas, shall be private motorized vehicles and therefore create unattractive connections (connected to *principle 8*). In the long run, core areas can be transformed towards "zero-emission zones" and therefore become accessible just for active modes or mode which are operated with electricity.

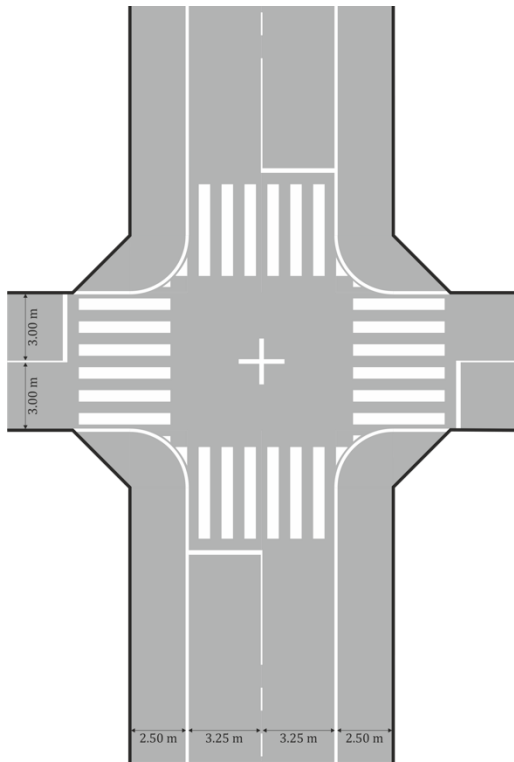
As a result, valuable space can be reclaimed from unnecessary roadways and parking and reallocated to more socially and economically productive uses. Regarding street design, Off-street parking shall be reduced, Driveways adequately integrated into a walk and cycle infrastructure which indicated clearly the right of way for the active modes. And Roadway areas needs to be minimized in order to make space for either cycle paths, corridors for road based public transportation or renaturation.

Measurements

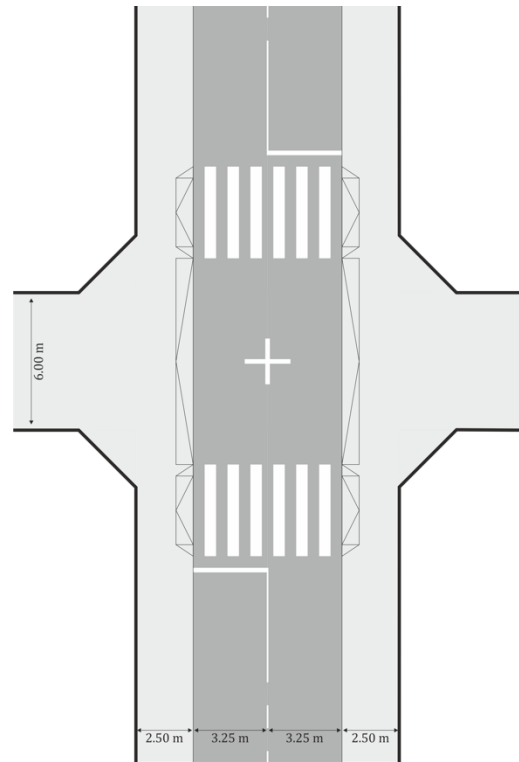
- *Establish and reach the long-term target of 150 Veh./1,000 Inh., including car sharing and taxi services.*
- *Define and establish a road hierarchy plan as part of the prefectural traffic management to guide and manage traffic flows in accordance to the guidelines of active mode development.*
- *Establish an integrated pricing catalog for the usage of roads (toll) and parking facilities (fine) which is based on road category, distance and travel speed as well as location and demand for parking.*
- *Establish a parking development plan to reduce and dismantle oversized roadways, off-street parking, car-parks and garages with the aim to re-purpose freed up areas towards walking, cycling, public transportation and urban developments.*
- *Establish an integrated and sustainable street design guideline of roadways with priority towards walking and cycling.*

FIGURE 6-1 | STREET DESIGN – EXAMPLES (1)

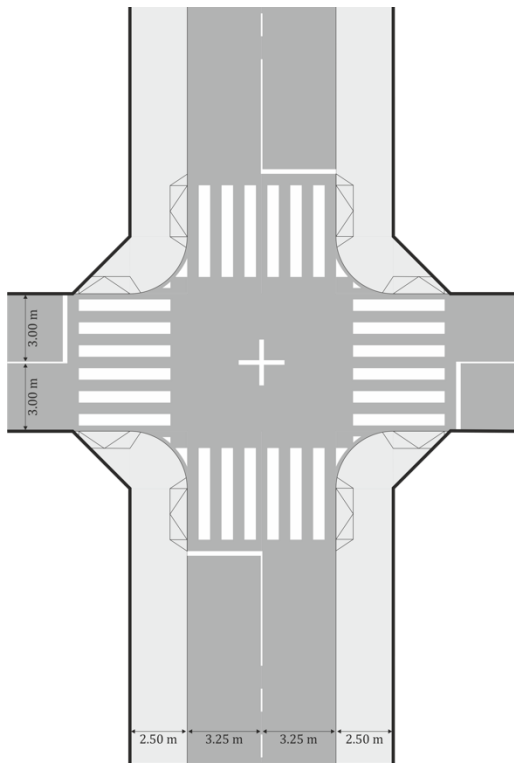
a) *Given design*



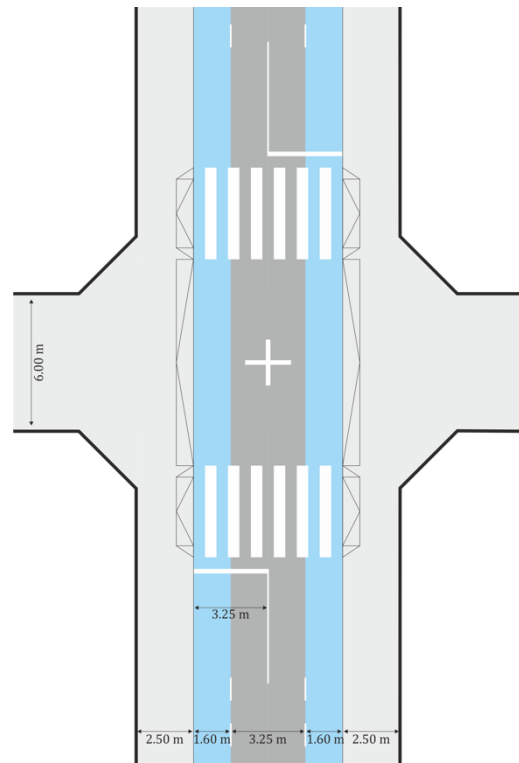
c) *Improved walkways along major road & minor street designed as 'shared space'*



b) *Improved walkways along major road*



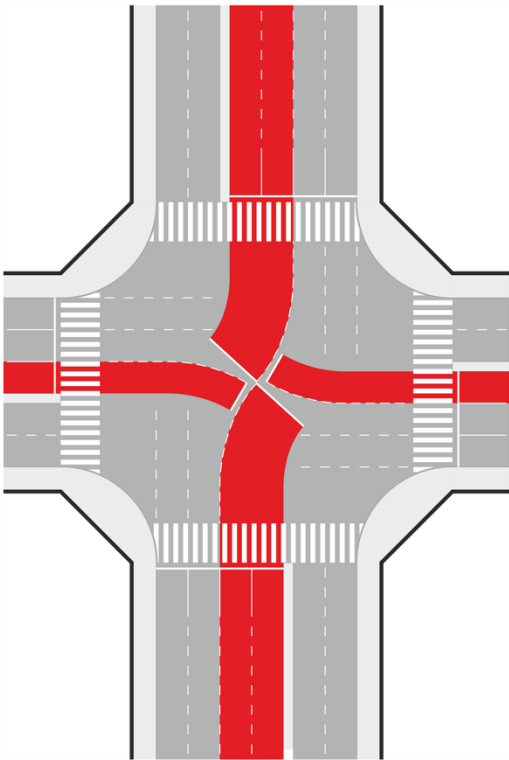
d) *Improved walk and bike ways along major road & minor street designed as 'shared space'*



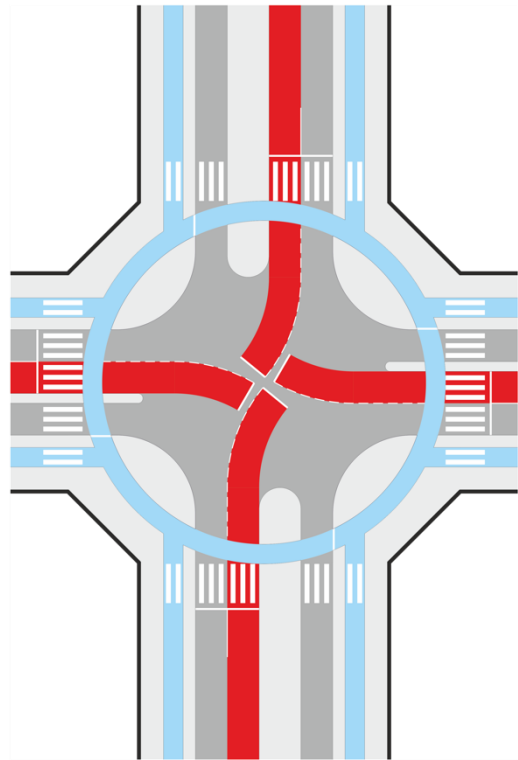
(source: own illustration, based on Wegman & Aarts, 2006)

FIGURE 6-2 | STREET DESIGN – EXAMPLES (2)

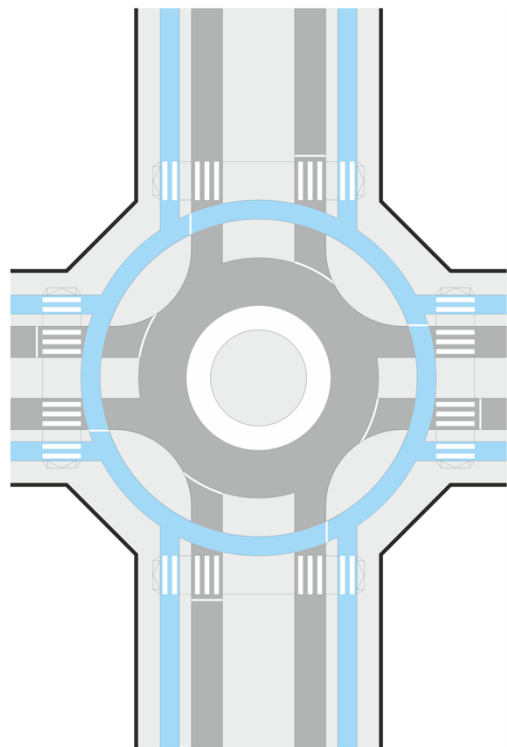
a) *Given design*



b) *Improved walk and bike ways along major road*



c) *Improved walk and bike ways along major road & interchange as 'mini-roundabout'*



(source: own illustration, based on Wegman & Aarts, 2006)

6.2.3 PUBLIC TRANSPORTATION

Principle 4

Public transportation is of high importance for efficient and equitable mobility. In addition, it requests but also supports dense and compact development patterns. It connects and integrates districts and quarters of a city as well as rural settlements with each other which are too far away to be accessed by walking and cycling. (ITDP, 2017)

Concept

In combination with walking and cycling (*principle 1,2 and 3*) public transportation shall be transformed to be the backbone of the prefectures sustainable transport system. In order to do so, trains and busses as well as stops and stations must increase in attractiveness. Attractiveness of Busses and Trains need to be of high quality in order to be the 1st choice to cover distances larger than it can be done by walking or cycling.

With respect to an aging society and urbanization, that aim results in barrier free boarding from platforms to vehicles, barrier free access towards platforms, high vehicle frequencies, full service coverage of settlements and their activities as well as accessible information which is easy to perceive and understand.

Along with the aim to increase ridership of public transport modes and frequencies, bottlenecks along the build modal infrastructure shall be removed and separate corridors for busses implemented, where needed.

Stations and stops shall receive a comprehensive design upgrade which aims for their reachability from all direction and easy platform access. They shall provide sufficient storage for bicycles, bike-sharing and easy interchange between other modes of public transportation (connected to *principle 1,2 and 3*). Stations, in addition, shall take over some urban functions of a settlement they cover such as local basic services (connected to *principle 7 and 8*).

Bus stops shall connect walking and cycling towards bus transportation. Therefore, such stops shall be built up more visible and provide sufficient bike racks to park private or shared bicycles (connected to *principle 1,2 and 3*). Each stop shall also be the access point towards local businesses and retails which cover the quarters basic services (connected to *principle 7 and 8*).

Tickets shall be affordable for every income, which as a result will further increases the attraction of the system. In addition, new forms of mobility, such as car- and bike-sharing and potential automated services shall be combined with classic public transportation (connected to *principle 3 and 5*). Aim is, that those interconnected services reinforce each other towards co-mobility, but not act as competitors.

The above conceptualized strengthening of classic public transportation and aimed interconnection with individual transport modes require a strong political back up which directly relates to a strong financial back up. Given transport finance policies shall be realigned in order to increase prefectural funds for public transportation. Two financial concepts could be considering to be implemented: One aims for an increased pricing for car usage and parking in urban areas. The other could aim for a Japanese adaptation of the French *versement transport*. A transport tax levied to the total gross salaries of all employees of companies. In the end, the financial support is of central importance about the quality of transportation.

People use transport modes more often when their demands and expectations are met. Therefore, participative and transparent transport development planning shall be implemented in order to further develop the network, routes, and headways. This is also of interest with the emerging digitalization which holds the opportunity for further demand-oriented services.

Measurements

- *Implementing a long-term Public Transport development plan including:*
 - (a) *Increase in service quality measured in service frequency, settlement and activity coverage as well as age-appropriate accessible information.*
 - (b) *Remove infrastructural bottlenecks and implement separated; exclusive corridors for Buses (Busways).*
 - (c) *Barrier-free redevelopment of Public Transport access points (stations and bus stops). This includes barrier free and all directional access to stops and stations by walking and cycling as well as barrier free access to platforms and from platform to vehicle.*
 - (d) *Relocate activities around stations and bus stops and establish them as central points of interest and local center of basic services.*
 - (e) *Realignment of the prefectural transport financial policies in order to increase prefectural funds for public transportation.*
 - (f) *Increase participation and transparency in transport development process to include ideas and demands of the local population.*

6.2.3.1 Rail bound Public Transportation – Concept & Measures

Infrastructure: The railway infrastructure shall be made able to handle double the amount of trains as of today. This mostly covers the area of the *Sendai MEA* and potential hubs such as *Ishinomaki* and *Fukooka*. Focus shall be laid on double tracks, depots and switches.

Network: The structure of a complete transport network is based on radial and tangential lines as well as adequate transfer stations, also seen as hubs (see Figure 6-3). A potential network extension is seen at the *Namboku* line of the Sendai Subway, which could be extended further north towards *Tomiya* and *Taiwa*.

Service: Three hierarchical services are intended (see Figure 6-4 and Figure 6-6):

- The **established railways services** (i.e. *Joban Line* or *Senseki Line*) refer to national and regional transport demands. This services only stops on selected stations.
- The **Miyagi Express (MX)** mainly fulfills the prefectural demands and usually serve all stations along a route. It covers all train services within the *Sendai Bay* area.
- **Sendai Subway** fulfills the local demand for mass rapid transportation in the *Sendai* area as already established.

Stations: In the entire prefecture stations shall be upgraded with the aim to provide easy and barrier free access from all directions by walking, cycling road based public transportation.

Vehicles: Due to aim to reduce greenhouse gasses and vehicle noise, railway vehicles shall be powered by electricity.

Where established overhead wire, *Electric Multiple Unit (EMU)* trains shall further be operated. *Diesel Multiple Unit (DMU)* on the other hand could be replaced by hydrogen powered trains.

A prototype of a fuel cell powered train, designed and constructed by Alstom, is the *Coradia iLint* currently tested in Germany. (Alstom, 2018)

Resilience: A station, mostly slightly elevated, holds the opportunity to include evacuation towers into their redesign.

And since most of the people will live not further than 10 minutes normal walking speed away from a station, railway transportation facilities hold the opportunity to become the first choice for vertical evacuation in case of tsunami evacuation. Trains run to the next station, and passengers run up the provided tower.

6.2.3.2 Road bound Public Transportation – Concept & Measures

Infrastructure: The future infrastructure shall be able to handle double the number of vehicles and passengers as of today. This can be reached by providing separate busways along major lines of the network and more attractive and functional stops and stations for waiting and transfers.

Network: The structure of a complete transport network is based on functional lines of radial and tangential connections.

Service: Two hierarchical services are intended (see Figure 6-7):

- The **prefectural bus services (BRT)** offers fast connections between settlements within and across the borders of the prefecture. This services only serves on selected stations and shall mainly operate on separate corridors. The concept is comparable towards the *Zuidtangent*.
- The **local bus services** (i.e. *Sendai Busses*) mainly fulfills the local demands and usually serves all stops along an inner-city route. During peak hours, the supply of vehicles is aligned on the demand.

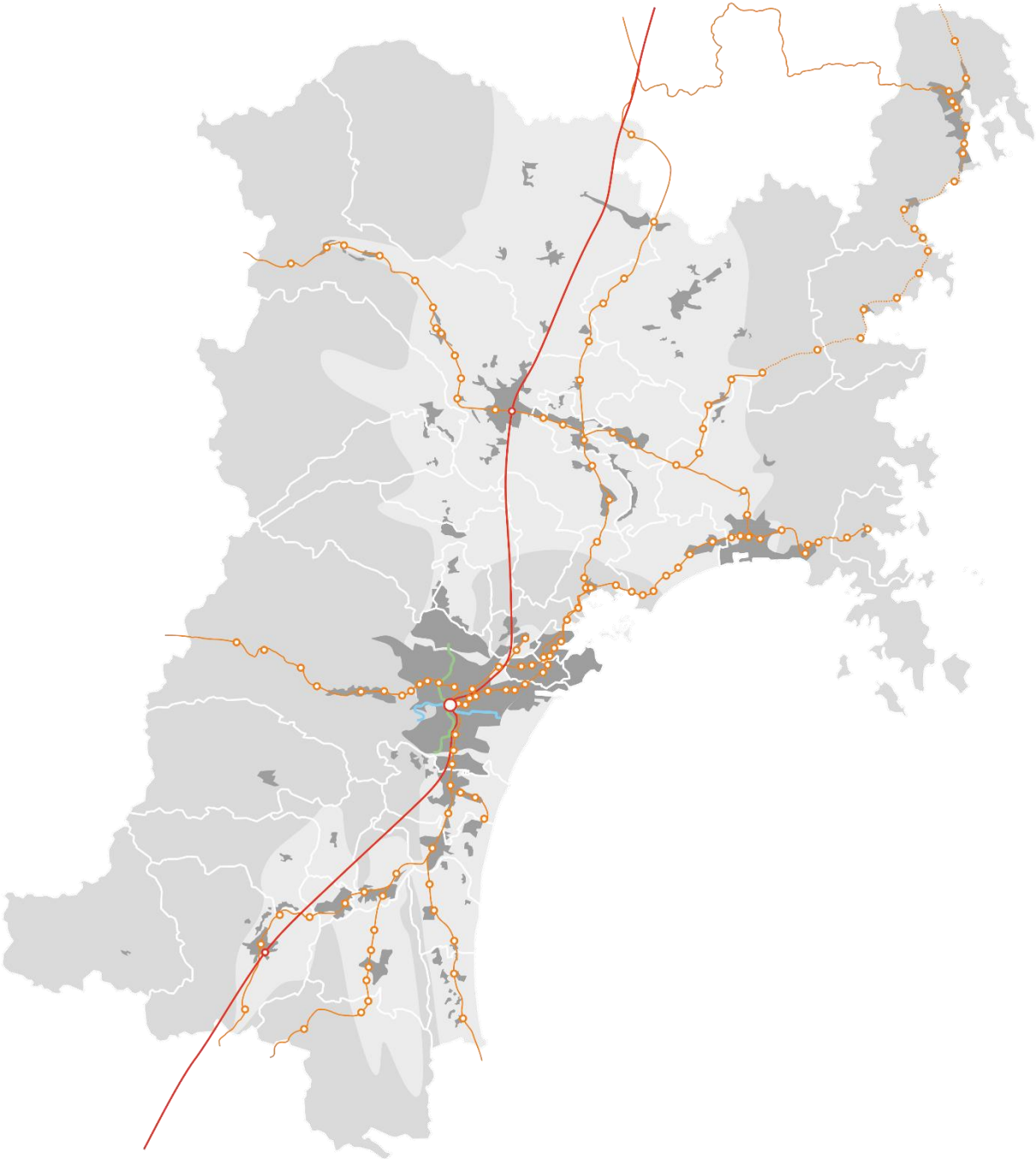
Operations: A separate corridor holds the opportunity to test automated operating bus services. In theory, the corridor provides a protected frame for the development of intelligent software for the automated driving. A pilot project could therefore investigate how automated and manual operated buses together could operate on prefectural and rural BRT system.

Bus-Stops: Stops of the entire prefecture shall be upgraded with the aim to provide easy and barrier free access from all directions by walking and cycling.

Vehicles: An alternative towards diesel powered busses is seen in hydrogen. Those busses run on electricity which is generated out of fuel cell. A prototype of a fuel cell powered electric bus, designed and constructed by Toyota, is currently operating in the *Tokyo* area. (Toyota, 2018)

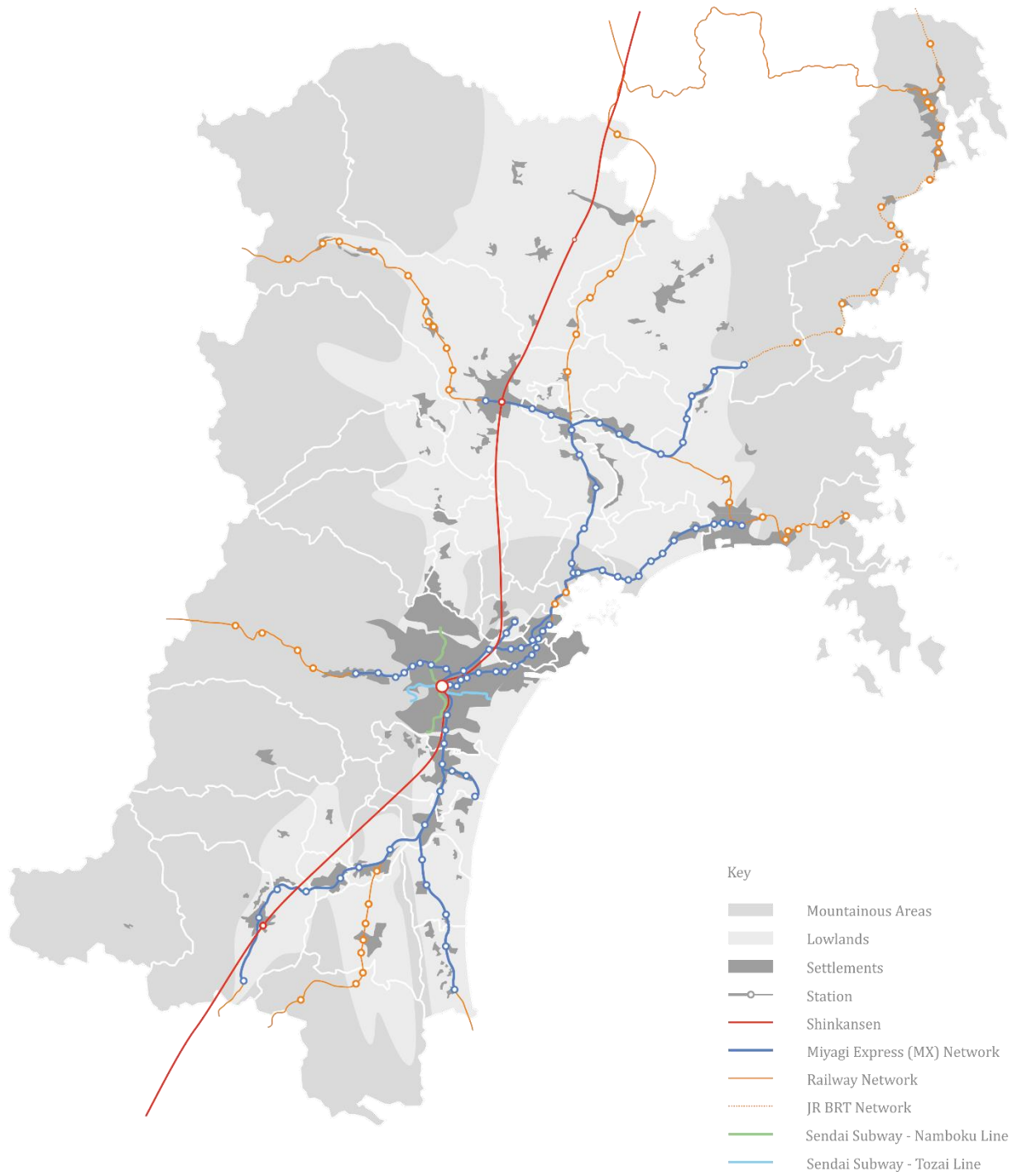
Resilience: The separated corridors for busses hold the opportunity be used in case of emergency.

FIGURE 6-3 | RAILWAY INFRASTRUCTURE NETWORK – GIVEN



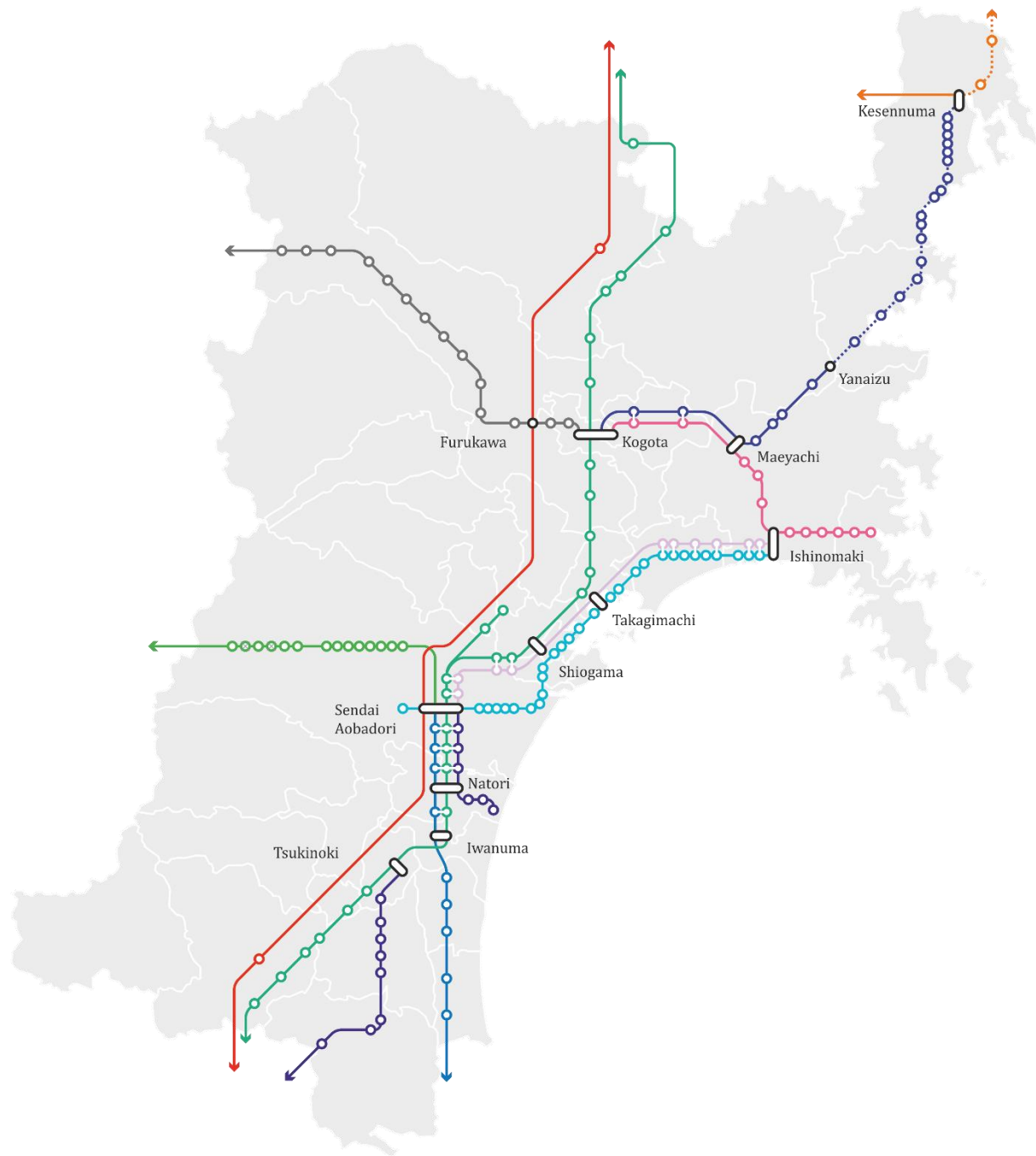
(source: own illustration, based and adapted from Miyagi Prefectural Government, 2013)

FIGURE 6-4 | RAILWAY INFRASTRUCTURE NETWORK – PROSPECTED



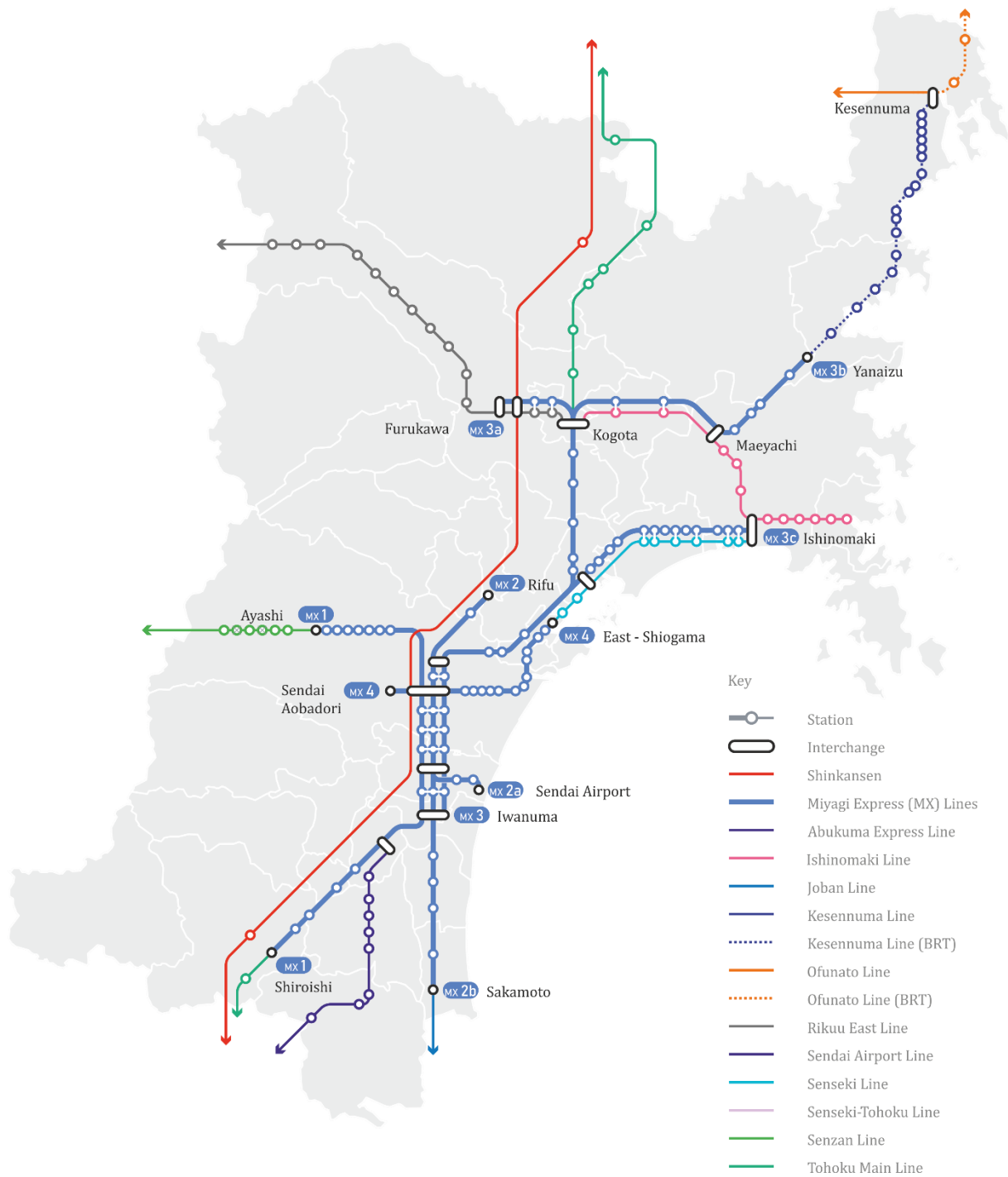
(source: own illustration)

FIGURE 6-5 | RAILWAY SERVICE NETWORK – GIVEN



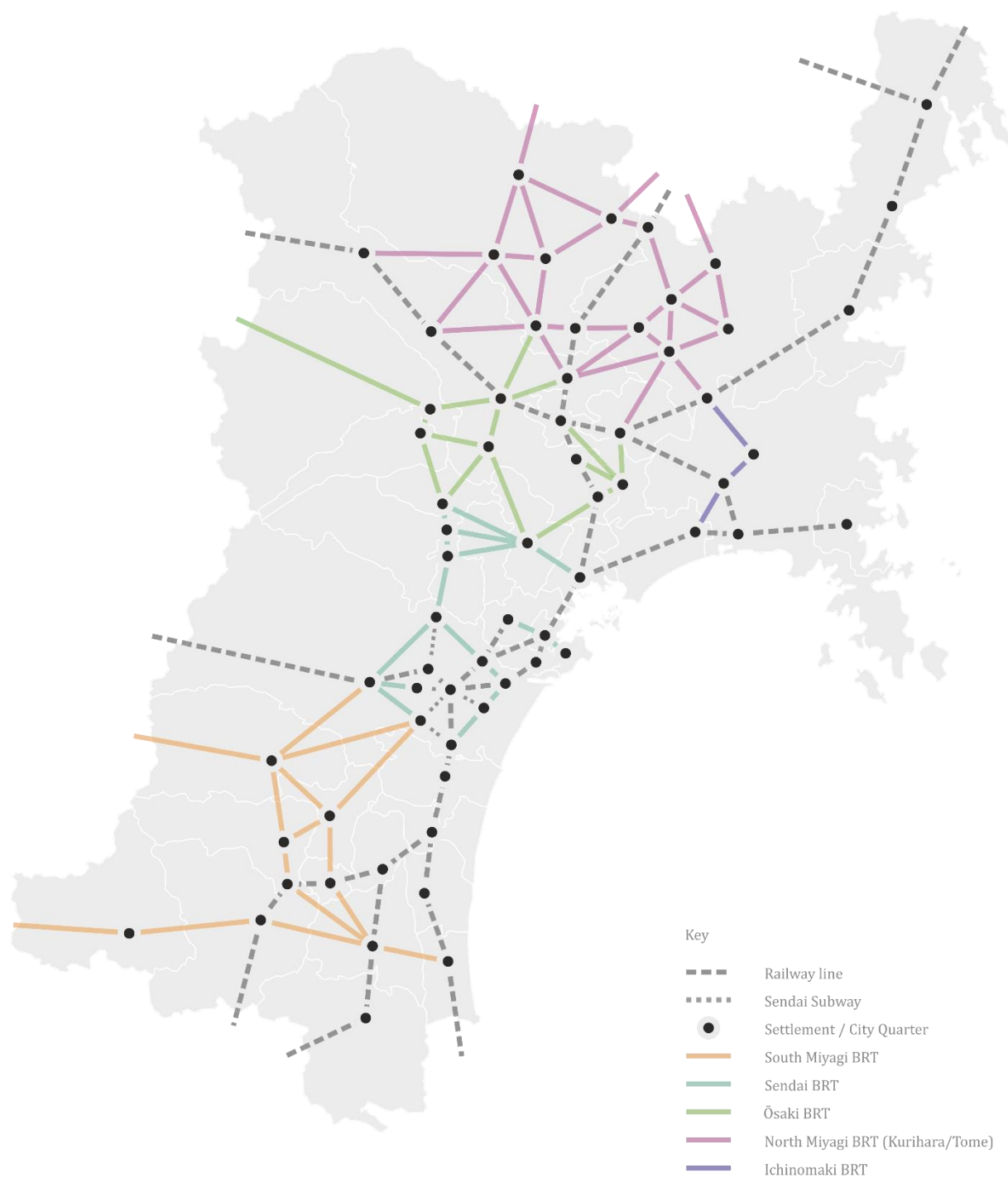
(source: own illustration, based and adapted from Miyagi Prefectural Government, 2013)

FIGURE 6-6 | RAILWAY SERVICE NETWORK – PROSPECTED



(source: own illustration)

FIGURE 6-7 | BRT SERVICE NETWORK - PROSPECTED



(source: own illustration)

6.2.4 COMPACT DEVELOPMENT

Principles 6, 7 and 8

Many people are drawn to move towards cities. Their aim is to find an adequate spatial proximity between living, working, leisure and regeneration. As a result, cities provide a certain set of activities which attract young and old at the same time. (Nakanishi, et al., 2013; ITDP, 2017)

One major factor for attractive, efficient and balanced settlements is a certain level of density of inhabitants and jobs per settlement or city quarter. (Nakanishi, et al., 2013; ITDP, 2017)

Each settlement in Miyagi plays an important role as point of attractions. Either for its own but also as part of the prefecture's identity as a whole. The historic development of each settlement, dense path network and the settlements green and agricultural surroundings give each community a distinct appearance. (Nakanishi, et al., 2013; ITDP, 2017)

Concept

Within Miyagi, the concept of **compact development** aims for the redevelopment of abandoned sites and areas currently un-used or used as parking lots. All of which shall be re-developed based on the aims of densification and functional mix.

The concept of **densification** and transformation as part of a local land use policy is to create new forms of dense housing typologies inspired by traditional Japanese buildings. This is in order to increase the diversity of housing and their connection to the local environment. This can be realized by the relocation measures taken after the tsunami, or the distribution of Land as laid out by Ohno Hidetoshi in *The Japan Architect* volume 63 (Ohno, 2006, pp. 35-39)

Dense, but also **functionally mixed** quarters and settlements encourage a creative and vibrant interaction of its inhabitants. Daily and periodic destinations, such as basic services, areas of regeneration, leisure or food, can easily be undertaken by walking and cycling due to a balanced distribution of urban functions. Diverse functions, which also appear over different times of the day, keep urban environment active and safe over the entire day and thus, create an area where people would like to live.

A further aspect is to concentrate inhabitants along access points of public transportation and to provide a complete coverage by road based public transportation. In this context, it is not the aim to increase coverage with an enlarged service. Coverage shall be increased by the coordinated shrinkage towards access points of public transportation.

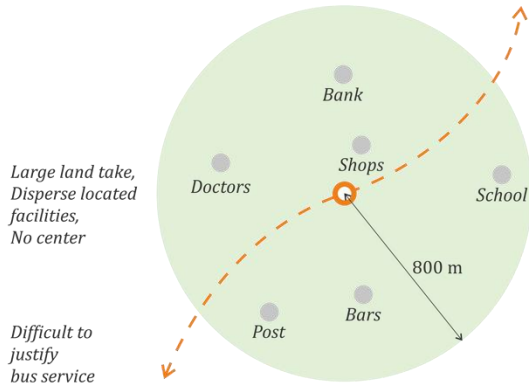
That shall result in a **contraction** of settlements around their central core or axis which the settlements developed itself from. **Fragmentation** of settlements shall strengthen the sub-centers and provide access of new urban green and water ways, aiming for renaturation in settlements (see Figure 6-8).

Measurements

- Compact settlements in a long-term Land Use re-development plan shall focus on the following:
 - (a) The Urbanization Promotion Area (UPA) shall be derived based on targeted population density and projected population growth. The build-up area outside the re-derived UPA is projected to be decommissioned.
 - (b) A guideline and town management plan shall guide the transfer of ground ownerships as well as coordinate decommission towards compact cities around train stations and bus stops.
- Zoning planning shall include the following measurements towards spatial density:
 - (a) Core areas (areas which have historic and ideological value towards the community) are areas where an inner development and a significant population growth is desired and possible.
 - (b) Revitalization of abandoned sites and areas currently used as parking lots with medium rise and medium converge build-up developments.
 - (c) Target for an average population density in the build-up area of each settlement is to be 8,000 Inh./km² or higher. In accordance, a 'medium rise & coverage' block structure shall be aimed for.
 - (d) Maximum distance to the nearest high-capacity collective transport access point (i.e. train station or BRT Stop) is 800 meters (10-minute walk). To the nearest local bus services 400 meters (5-minute walk).
- Zoning planning shall include the following measurements regarding functional mix:
 - (a) Adequate ration between residential and non-residential usage within the catchment area of stations and bus stops.
 - (b) Preservation of existent housing and established local businesses in combination with the reconstruction and conversion of abandoned sites for mixed-use developments (i.e. workspaces, education, institutions, services and lining).
 - (c) New development shall provide affordable housing, living for elderly and local public services (i.e. shops for daily needs, pharmacies and medical care)

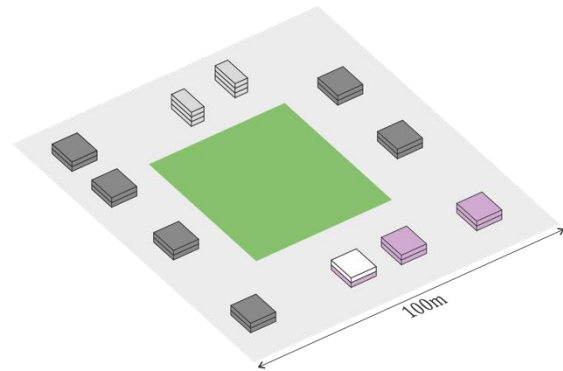
FIGURE 6-8 | COMPACT DEVELOPMENT

(a) population density: 2,000 Inh/km²
inhabitants: 4,100
area: 200 ha

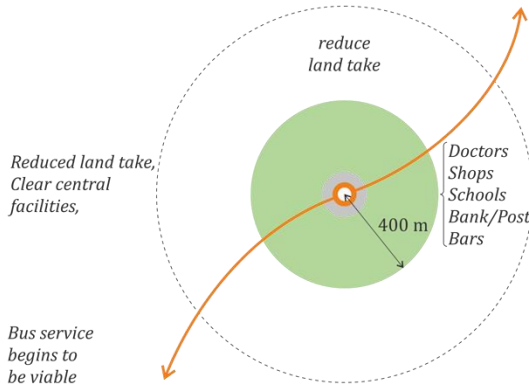


dwellings: 9 per ha

low rise - low coverage

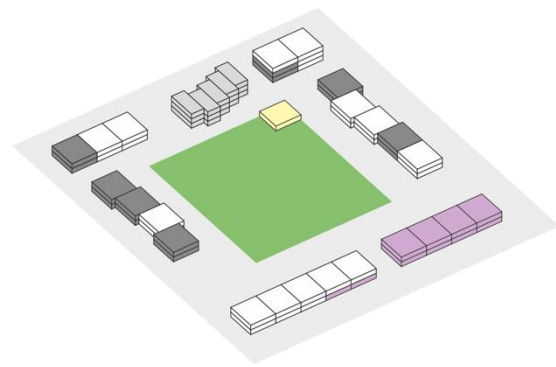


(b) population density: 8,000 Inh/km²
inhabitants: 4,100
area: 50 ha

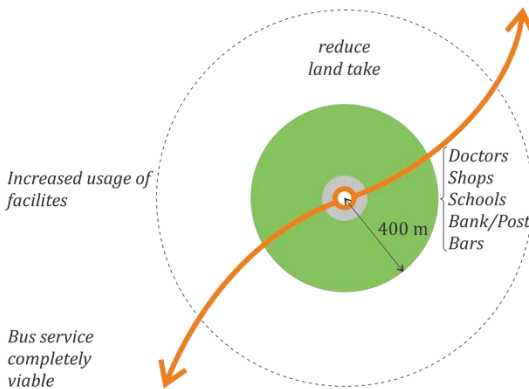


dwellings: 36 per ha

low rise - medium coverage

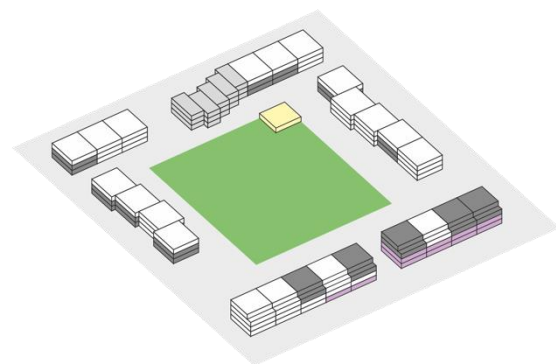


(c) population density: 14,000 Inh/km²
inhabitants: 7,037
area: 50 ha



dwellings: 64 per ha

medium rise - medium coverage



- Maisonettes
- Houses
- Aparments
- Community facilities
- Shops and workspaces

(source: own illustration, based on (Rogers, 1999) Berghauser Pont & Haupt, 2010; Fernandes Per & Mozas, 2004)

6.3 DISCUSSION & CONCLUSION

Requirements for the development of the before This chapter determined the requirements for the development of the before described *prospected* and desired transport system.

The identified requirements lead to introduction of the development principles of *Transit Oriented Development (TOD)*. As defined and provided by the Institute for *Transport Policy and Development (ITDP)* (2017).

Having a closer look, it can be concluded, that the first five principles mainly relate to *transportation* policies, while the last three mostly relate towards land use policies.

Out of the introduced principles, *four* development concepts were derived. All with the aim to keep clarity and further comparability to other cases. Many of the advised measurements are not new and generally known by decision makers and planners or decades. Nevertheless, their relevance is still given since most of them are not well implemented yet.

It therefore can be concluded, that sustainable transportation and compact cities are concepts which are based on the implementation of a number of individual measurements. One measurement on its own has low impact. But in combination their synergies unfold. Particular focus on service quality therefore shall be set towards transport hubs or access points, where people enter, egress and change modes.

At the current state, the development of the ideal case of Miyagi cannot be named in detail. It is for this reason, that the here provided summation does not claim to be complete.

Nevertheless, the following insights can be concluded for the identified design fields:

1) *Street Design* (Principles 1, 2, 3 and 5)

... aims to balance different type of user and modal expectations that various groups place on the scarce resource of '*public space*'.

Major target in the prospected transport system it the decrease of private motorization and increase of walking and cycling as the major mode of choice. In order to do so, a strong and sufficient walk and cycle network must be implemented. In the end of the DTL-cycle, street design shapes traffic and transportation.

2) *Design of Public Transportation* (Principle 4)

... aims to provide a high-quality service, which directly relates to network design, infrastructural separation and priority in traffic.

Within Miyagi, the given railways system can be developed further into the backbone of the prefectures transportation. Required is a more *frequently* served network, fed and supported by a dense network of prefectural bus services which operate on their own guideways. Service quality, appearance and coverage of public transportation influence the modal acceptance.

3) *Design of Compact City* (Principles 6, 7 and 8)

... aims for the balance of different functions and activities that various groups place on the scarce resource of available space. This directly relates to transport infrastructure and housing typologies.

Furthermore, bus stops and train stations will become *a) mobility hubs* which provide easy and guaranteed connections towards many other modes as well as *b) central squares* of basic services for daily use and social interaction.

Shrinkage will be coordinated towards stops and stations of collective transport modes. All in order to provide *concentrated* and *fragmented* compact settlements which provide minimum population densities and mixed functionality. The compact design of settlement directly influences mode choice.

FIGURE 6-9 | SUSTAINABLE STREET DESIGN

Example 1:



Example 2:



(Source: own illustration based on Streetmix, 2018)

7 IMPACT ANALYSIS

Final step of the backcasting approach is the analysis of the derived designs impact. The concept and the derived designs are evaluated towards their impact regarding the sustainability goals, objective groups and targets as derived in chapter 2 (p. 13).

The combination of the *sustainable transportation goals* (Litman, 2016), *sustainable development objectives* (SuM4All, 2017) and the *Avoid, Shift, Improve* guideline for the sustainable transport, development (United Nations, 2016) was set as the strategic foundation for the development of an age-friendly but also age-independent transport design in chapter 5 (p. 33) and is here the aimed quality for the ideal case.

The regional transport system pointed out in Chapter 6 (p.45) is based on innovative but not completely new solutions which aim to guarantee the *mobility needs of all age and population groups* and to support a regions thrive when facing an uncertain future with economic, social, and environmental shifts. If these designs are capable to provide sustainable transportation for the decades to come is part of this chapter.

The following subchapters evaluates the aforementioned derived design concepts and measurements based on expert judgment and the gained insights of the afore performed literature reviews.

Each subchapter is dedicated to one of the design concept and related measurements and each evaluates on the concepts impact towards economic, social, and environmental aspects.

7.1 ACTIVE MODES

No other mode of transportation contributes towards health, climate and environmental protection, reduction of occupied space as well as low demands on resource and energy than the modes of walking and cycling.

A significant increase on active trips should therefore be supported by adequate policies and measurements of each municipality.

Walking is the start and end of every transport chain, and the design quality of walk and bike ways directly influences the mode choice towards walking and cycling.

Especially elderly are highly sensitive to the quality of walk and cycle ways and can be easily discouraged to be active when they have to detour. As a result, people are particularly sensitive to network density and the directness of provided ways. Aspects of provided space, the paths separation from motorized traffic, access to a variety of activities and weather shelter by urban structures or trees increase the quality of a walk or ride with the bike.

A major quality indicator for active and attractive **urban** settlements, are the amount of people on the streets. Basic requirements for active settlements are walkable quarters and safe crossings. An **urban** design that is more permeable to pedestrians and cyclists than to private motorization encourages the use of active modes and public transportation with all the associated benefits. A condition which counts for growing as well as shrinking cities.

As soon as a network of paths and streets offers multiple routes to many destinations as well as frequent street corners, narrower rights of way and slow vehicular speeds than walking and cycling trips become varied and enjoyable

Connectivity is a synergy between **transport system** related design of neighbourhood connecting and accessing streets with **land use** related planning towards the adequate size of development zones.

I. Economy

- *Transport system efficiency increases due to wider designed and curb separated walk and bike ways. Service reliability, punctuality, travel speed and performance increase due to direct and continuous designed cross ways and driveways which dedicate priority for active modes.*
- *Transport system integration is increased due to a clear hierarchical structure of homogeneous designed walk and bike ways as well as the classification of narrow side streets as 'shared space' with priority of active modes.*
- *Accessibility to transportation increased due to a clear, attractive and inviting design of walk and bike ways.*
- *Economic and business developments increase, due to an increased accessibility to education, employments and local industries located along walk ways and pedestrian only zones.*
- *The efficient operation of walk and bike ways increases cost efficiency, since operational cost and need of investments declined, due to the systems lower life cycle costs.*

II. Social:

- *Smaller blocks and interconnected streets accommodate all users, including those with disabilities or low incomes due to their interconnection with other modes. Handicapped people participate in social activities and are independent from the help of other.*
- *Physical and mental health is increased, due to being outdoors with an active move on a high-quality walk or bike way.*
- *Crashes, traffic casualties or assaults are minimized, due to short distances between blocks, which also reduce vehicle speeds, as well as separate infrastructure.*
- *Areas for walking, cycling as well as public squares create urban places to interact and encounter each other resulting in inclusive and attractive communities and support for cultural activities.*
- *Connectivity of blocks as well as public squares links different quarters of town and therefore helps to interconnect and encounter an inclusive and attractive community with support for cultural activities.*
- *The community's cohesion is increased due to well-connected and integrated walk and bike ways as well as the quality to stay at public squares. It interconnects people of different social classes and therefore creates coherent societies.*

III. Environmental:

- *By walking and cycling the global warming emissions are reduced, impacts of climate change are mitigated, traffic noise exposure and water pollution is reduced and high-quality habitats get preserved.*

7.2 SHIFT

No other mode is as harmful towards health, climate and environmental protection as well as demanding on open space and energy than the modes of private motorization.

A significant decrease on private motorized trips should therefore be supported by adequate policies and measurements of each municipality.

At the current state, no other mode is as well established in the given transport system than the private car which directly influences the mode choice towards it.

Especially elderly are highly sensitive towards driving while their willingness to drive decreases the older they get.

A major quality indicator for active and attractive **urban** settlements, is the number of cars on the streets. Basic requirements for active settlements count on the correlation of “the less, the better”.

Less cars in a settlement relates to less noise, pollution, and spatial occupation. The absence of private motorization helps to increase green and blue areas for climate protection and encourages a compact development of settlements as pointed out in chapter 6.2.4, p. 59.

I. Economy

- *Transport system efficiency increases due to a reduction in private motorization, adequate street design and hierarchy as well as priority of active modes over private motorization.*
- *Reliability, punctuality and performance increases due to a clear and self-explanatory street design.*
- *Transport system integration is given since more street space is given to collective transportation (busses) and non-motorized modes (walking, cycling and bike-sharing).*
- *Accessibility to transportation increased since narrow side streets are classified as ‘shared space’ with priority of active modes.*
- *Economic and business developments increase, due to an interconnected network of walk and bike which provide access to employments and local industries.*
- *Energy costs and usage of petroleum are reduced, since the reduction of private motorization and the switch towards hydrogen powered vehicles lowers the energy consumption per capita.*
- *The efficient operation of traffic and transport infrastructure increased cost efficiency, since operational cost and need of investments declined due to a lower utilization of roads by private automobiles.*

II. Social:

- *A sustainable street design accommodates all users, including those with disabilities or low incomes due to their equitable street design for all modes and barrier free crosswalks.*
- *Crashes, traffic casualties or assaults are minimized, due to a) self-explanatory, clear road infrastructure, b) short distances between blocks, which also reduce vehicle speeds and c) due to reduced traffic volumes and improved technologies.*
- *The functional mix along roads and walk ways creates inclusive and attractive communities and supports cultural activities.*
- *The community’s cohesion is increased due to well-integrated walk and bike ways which increase the quality to stay as well as parking garages which are integrated in urban structure.*

III. Environmental:

- *Global warming emissions, traffic noise exposure and water pollution are reduced due to the reduction of private motorization and usage.*

7.3 PUBLIC TRANSPORTATION

Public transportation connects and integrates people with the city beyond the range of walking and cycling.

It is also critical for people to access the largest pool of opportunities and resources. *“Highly efficient and equitable urban mobility and dense and compact development patterns mutually support and reinforce each other.”* (ITDP, 2017)

Collective transportation has the lowest impact on the environment measured per capita and as part of motorized vehicles. Required, that the usage is on an adequate level.

Collective transportation requires no further knowledge in order to use them apart from the process of how to acquire a ticket and the knowledge of the given service network. It therefore offers mobility for people of all age, mental capabilities and social status.

A major quality indicator for active and attractive **urban** settlements is the design of Stops and Stations. Their development towards intermodal hubs will greatly improve accessibility and mobility in the prefecture.

A network of clear defined lines generates an efficient service. It allows direct relations to the center and between all important quarters of a settlement without interchanges (main lines) or with only one interchange (secondary lines). In the end, the system also takes advantage of the rather bundled structure of traffic relations and flows with positive impact on social urban development and environmental impacts. (Nakanishi, et al., 2013; ITDP, 2017)

In combination with a coordinated shrinkage around transport access points, train stations can be expanded with evacuation towers. In case of a tsunami, those towers are just 10 minutes normal walking speed away from anyone’s home.

I. Economy

- *Transport system efficiency increases due to a decline in private motorization and increase in public transport ridership.*
- *Service reliability, punctuality, travel speed and performance increase due to more frequent services on exclusive and separated carriageways.*
- *Transport system integration is increased due to the mobility stations which combine individual modes (walking, cycling, car- and bike-sharing) with collective modes (railways and busses)*
- *Accessibility to transportation increased due to densified developments around stops and stations, longer services hours and affordable fares.*
- *Economic and business developments increase, due to an increased accessibility to education, employments and local industries located in the catchment area of stops and stations.*
- *Energy costs and usage of petroleum are reduced, since the implementation of a balanced transport system and the switch towards hydrogen powered vehicles lowers the energy consumption per capita.*
- *The efficient operation of traffic and transport infrastructure increased cost efficiency, since service quality increased of the above-mentioned measures and operational cost and need of investments declined, due to a higher ridership and system coverage.*

II. Social:

- *Public transportation accommodates all users, including those with disabilities or low incomes due to their interconnection with other modes (mobility station) and high-quality barrier free access to stops and stations as well as level boarding of vehicles.*
- *Crashes, traffic casualties or assaults are minimized, due to separate infrastructure, active stations and traveling in a group.*
- *The functional mix at stations and around bus stops creates inclusive and attractive communities and supports cultural activities.*
- *The community’s cohesion is increased due to well-integrated walk and bike ways as well as the quality to stay at stops and stations.*

III. Environmental:

- *By the use of hydrogen powered vehicles, the global warming emissions are reduced, impacts of climate change are mitigated, traffic noise exposer and water pollution are reduced and high-quality habitats get preserved.*

7.4 COMPACT SETTLEMENTS

Under condition of shrinkage, a coordination of settlement development with transport infrastructure and supply planning is required, which promotes a minimum population density of urban structures of at least 8,000 Inh./km².

Especially when considering an exponential increase in financial effort to sustain traffic infrastructure and public transportation, the provision of minimum densities is necessary for services of general interest in order to secure economically viable public transportation and thus to ensure the accessibility of all services to public interest.

Westphal concluded, that only by decommissioning an active and long-lasting future-proof quarter cannot be assured. It is the combination of decommission and improvement (overall concept **Compact Development (A)**, p. 43) with the re-naturalization of areas which get free is of importance (overall concept **Green Environment (B)**, p. 43)

Neighborhoods that follow that design are thought to lower the use of the car and encourage people to walk, cycle or use public transportation. (Chorus, 2012, p. 33)

I. Economy

- *Transport system efficiency increases due to shorter proximities between activities (such as working, living, leisure or regeneration), increase in collective transport ridership, decline in private motorization and as well as priority of active modes over private motorization.*
- *Reliability, punctuality and performance increases due to an increased usage of active modes, self-explanatory street design and more frequent collective transport services on exclusive and separated carriageways.*
- *Transport system integration is made possible, since a functionally mixed and dense quarters encourage the usage of non-motorized modes (walking, cycling and bike-sharing) and collective transportation (busses and railways) for distance which cannot be covered by active modes.*
- *Accessibility to active modes and public transportation is increased due to dense and functionally mixed developments around stops and stations.*
- *Economic and business developments increase and are strengthened for an unsure future development, due to shorter proximities between working and living and the balance between individual and collective transportation.*
- *Energy costs and petroleum usage are reduced, due to the denser and functionally mixed urban*

structure and the decommission of low-dense quarters in the outskirts. Due to shorter distances, less energy is needed for any form of transportation, which further reduces cost and fuel consumption per capita.

- *The efficient operation of traffic and transport as well as the efficient operation of urban infrastructure increased cost efficiency, since a reduced road network and denser urban structures demands less maintenance and investments, which lowers operation cost per capita.*

II. Social

- *A compact urban structure accommodates all users, including those with disabilities, high age or low incomes due to shorter destination between activities and the availability of multiple interconnected transport modes.*
- *Compact Settlements provide a high density of housing and activities which can be reached via short distances, which supports walking as primary mode of choice and helps to increase public health. In return, crashes, traffic casualties or assaults are minimized, due to a lower exposure to traffic.*
- *An adequate mix of functions, dense urban structure and interconnected transport modes provide a sufficient number of citizens in order to secure services of general interest as well as economically viable public transportation. Thus, adequate densities and mix of functions provide inclusive and attractive communities which support cultural activities and the community's cohesion. As a result, cultural resources and traditions can be preserved.*

III. Environment

- *A compact settlement reduces global warming emissions due to shorter distances between activities and the related increase of active modes.*
- *Climate change impacts can be mitigated when areas outside the contraction areas are re-naturalized.*
- *Water pollution is minimized, due to a reduction in fuel consumptions, based on a dense and functionally mixed settlement as well as the use of hydrogen powered vehicles.*
- *Impervious surface area is minimized due to the decommission of former low-dense quarters within a smart-contraction program.*
- *Global warming emissions are reduced due to shorter distances towards activities and its related influence in the increased usage of active modes. Density and a functional mix mitigate indirectly towards climate change impacts, reduces traffic noise exposure and water pollution.*

7.5 DISCUSSION & CONCLUSION

Elementary contribution of this chapter was the to analyze the scenarios impact towards the derived sustainable transportation goals (*Backcasting Step 2*). Furthermore, its analysis the impact of the four derived development concepts identified in the chapter before (*Backcasting Step 6*).

This is done by considering the DTL-circle in the evaluation process. Each measurement which changes the transport system, influenced Land Use and peoples demand for certain modes.

If a scenario does not live up to the goals identified in Step 2, it will not be considered as a desirable future. It's insights however iterate towards Step 2 and 5. The purpose of that iterative step was to derive the desirable requirements and measurement which is needed to fulfill one part of the sustainable transportation goals.

At the end, and as presented in this thesis, it summarized the impact of each requirement and concept (*Backcasting Step 6*) towards the derived sustainable transportation goals (*Backcasting Step 2*).

The following identified *field-of designs* and their impacts in relation to the identified *object groups* are summarized as follows:

1) *Impact of Street Design* (Principles 1, 2, 3 and 5)

Universal Access (UA) is achieved by an intuitive, self-explanatory and attractive street design, which gives more space towards active modes and road based public transportation. Their integration is increased due to a clear hierarchical structure and a homogeneous design.

Street design impacts *Efficiency (EF)*. Services are more reliable, punctual and faster due to modal separation. Furthermore, energy cost reduces due to smother driving. Operational cost and the need of investments decline, because of lower traffic volumes. Sustainable street design accommodates all user groups, due to barrier free construction. *Safety (SA)* increases due to lower vehicle speeds, reduced traffic volumes and adequate space for active modes.

All of which aids towards Green Mobility (GM). Emissions, traffic noise and water pollution decline.

2) *Impact of Public Transportation Design* (Principle 4)

Universal Access (UA) is achieved by providing mobility stations which combine individual modes (walking, cycling, car- and bike-sharing) with collective modes (railways and busses).

More frequent services, punctuality and higher travel speed increase the performance of public transportation and so its *Efficiency (EF)*.

Energy cost decline due to collective transportation, as well as operational costs. *Safety (SA)* increases due to separate infrastructure, active stations and traveling in groups.

Traveling in groups supports *Green Mobility (GM)*. Emissions, traffic noise and water pollution declines. Shifting to modes of public transportation can mitigate the effects of climate change.

3) *Impact of Compact City Design* (Principles 6, 7 and 8)

Universal Access (UA) to active modes and public transportation is increased due to a dense and functionally mixed development around bus stops and train stations.

The *efficient (EF)* operation of urban infrastructure increases cost efficiency, since a reduced transport network and denser urban structure demand less maintenance and investments, which lowers operational costs and fuel consumption per capita. Walking as a primary mode of choice increases public health. In return, crashes, traffic casualties and assaults are minimized. The compact city is *safer (SA)*, due to a reduced exposure to traffic and the social over watch.

Spatial density and a functional mix of activities directly impacts *Green Mobility (GM)*. One effect is the positive impact on mode choice which shifts towards active modes, reduces traffic and its related exposure to emissions and pollutants. A coordinated

Relation to "Avoid - Shift - Improve"

A sufficient and sustainable street design is seen as contribution to *shifting*, the 2nd step in the approach. The design contributes to use more environmentally friendly modes such as a combination of active and public modes (i.e. multi-modality).

The development of a sufficient railway service and network is mainly understood as contribution toward the *improvement* of modes, the 3rd step of the approach.

The development of a sufficient and attractive railway system, also promotes *shifting* towards it. The sustainable roads design also relates towards the infrastructural *improvement* of active modes. Therefore, shift and improve are related to all transport systems.

The 1st step of *avoiding* transportation mostly relates to the concept of compact cities. Its density and functional mix of activities prevents unnecessary trips and supports less complicated transport chains.

It is therefore, that compact cities have the most importance towards the development of sustainable transportation.

PART FIVE

GENERALIZATION

The *Backcasting* approach was chosen as underlying methodology and structure of this thesis. It was selected with the aim to build and describe a desirable sustainable transportation system which support a region thrive when facing an uncertain economic, social, and environmental future.

Within this thesis, two major aspects were added towards the backcasting approach. *The first*, is the consideration of forecasted population and aging trends. *the second* is the evaluation of the prospected designs along the reinvented 'land-use and transportation feedback circle' (DTL-circle). A consideration, which has not been performed before.

This chapter reflects on the outcome of the applied *backcasting* approach and how its insights can be generalized towards other areas of the world, which face or are about to face similar trends of de-population and aging.

Step 1: Objectives

This step of the backcasting analysis is a short overview over the research's *purpose, scope* and potential *development*. The chapter builds a general structural overview but its content is case specific towards the research.

This step, seen as a general introductory towards the chosen approach, could increase comparability between studies and ease finding relevant research.

Step 2: Goals and Targets

Within this step qualitative goals, objectives and targets of sustainable transportation policies are introduced as foundation for the upcoming scenario analysis (*Backcasting Step 5*). General aim of sustainable transportation is to balance *economic, social* and *environmental* aspects. In addition, these aspects were combined with qualitative development indicators which lead the direction of each aspect.

The insights of this derivation are also declared as the strategic foundation for any future development of traffic and transportation. The identified indicators show the direction for the quantitative development of each mode.

The field of urbanism increases that point of view by adding the aspect of *design* as a fourth aspect to sustainability in order to describe the quality of the realized project.

Overall, the development of transport modes and infrastructure follows a *guideline* which *avoids* unnecessary motorized trips, *shift* towards environmentally friendly transport modes, and *improves* them by considering the *quality of design*.

Sustainable transport planning, as described above, is applicable towards any case study in the world. Each place, regardless if it is rural village or buzzing city, aims for the balance which sustainable transportation planning is offering.

However, every place is different in terms of topography, urban structure, socio-economics, policies and societal preferences. And therefore, each place needs its own strategy for the fulfillment of sustainability goals.

Step 3: Present System

This step introduced and described the available *transport modes* which form the very specific *transport system* of the Miyagi prefecture. The content is case specific. Due to a lack of available data, this chapter is elaborated in a qualitative way; focusing on the *system characteristics* of the given transport modes and their modal interconnection.

Nevertheless, *number of trips* and *modal split* indicates the specific case related traffic and transport demand. This Analysis helps to indicate the degree of intermodal efficiency.

Each case study has a different transport system, and their characteristics therefore very. All of which results in different transport system efficiencies as well as driving forces for its further development.

Step 4: External factors

Within this thesis and connected to the Miyagi case, *aging* and *shrinkage* has been the identified as external factors influencing the transport system. These factors mainly impact developed countries and are therefore of interest for a lot of regions worldwide. Their elaboration here was of qualitative nature.

Nevertheless, any other external influencer towards the '*land use and transport feedback circle*' can be chosen and elaborated within this backcasting step. This step specifies what external factor is included into the Scenario Analysis (*Backcasting Step 5*). Each chosen factor is therefore case specific.

Step 5: Scenario Analysis

This step combines the insights gained out of the derived sustainable transportation goals (*Backcasting Step 2*), discussed given transport system (*Backcasting Step 3*) and its influencing external factors (*Backcasting Step 4*). It combines the former steps and elaborates potential scenarios for the future development of the given transport system.

This thesis elaborated two scenarios. One projective (*forecasting*) and one prospective (*backcasting*) scenario. However, any form and any amount of scenario analysis could be applied here. Either qualitative or quantitative and as many as needed. General aim of each scenario is to live up to all identified goals from Step 2, and if it does not, it won't be considered to be a feasible development.

Step 6: Implementation Requirements

The ideal, all goals fulfilling scenario (*Backcasting Step 5*), is compared to the present system (*Backcasting Step 3*). The identified differences between ideal and present system determines the system related requirements. Those are need to be realized in order to transform the given system into the ideal one. This step therefore indicates where institutional responsibility (policies) need to change in order to provide concepts which make the ideal scenario come true.

This step is rather specific and bond to each case. For instance, when the goal is to balance transportation, the Netherlands have to invest less into a sufficient cycling infrastructure than the Miyagi prefecture.

Nevertheless, general design principles where presented within this thesis. Those can be applied to any case in the world. The major aim of them is to prioritize the infrastructural implementation of walking and cycling over private motorization.

Step 7: Impact Analysis

At first, the last step analyses the impact of each derived scenario with respect towards the derived sustainable transportation goals (*Backcasting Step 2*). If a scenario does not live up to the goals identified in Step 2, it will not be considered as a desirable future. It's insights however iterate towards Step 2 and 5, with the aim to derive the desirable future which derives the requirements and measurements needed to fulfill the sustainable transportation goals.

At the end, and as presented in this thesis, it summarizes the impact of each requirement (*Backcasting Step 6*) towards the derived sustainable transportation goals (*Backcasting Step 2*).

In Conclusion

Backcasting in combination with the DTL-circle is a sufficient tool for any other case study in the world.

The backcasting approach, as presented within this thesis, provides a general frame for any research in the field of transportation. In combination with the DTL-feedback loop, this methodology indicates the direct impacts of measurements towards land use, demand and transport system.

The design principles (*Backcasting Step 6*), and the *avoid, shift, improve* approach (*Backcasting Step 2*) are general concepts, which results in specific development concepts and recommendations, when using the here presented backcasting and DTL-cycle.

Each step of the here presented thesis has the power to become a research on its own. Either in a general or specific context.

DISCUSSION

The aim of this thesis was to recommend designs for a regional transport system which is based on innovative solutions which is challenged by an ageing society, urbanization, depopulation, climate change and natural disasters. The transport system aims to guarantee the mobility needs of all age groups, especially the elderly, and to support the region thrive within an uncertain future due to economic, social, and environmental shifts.

In order to do so, the backcasting approach described by Geurs & van Wee (2004) was applied as underlying methodology and frame for the research's structure. The '*land use transport feedback cycle*' of Wegener & Fürst (1999), used as theoretical frame for the thesis, was expanded by dividing the section on transportation into two. One segment dedicated to Demand, the dedicated to the transport system itself. Both were elaborated further with Chorus' (2012) insight on development dynamics which are taking place within the feedback cycle. The feedback loop is referenced to during the entire research in order to evaluate policies, concepts and measurements who impact transportation, land use and demand.

Starting point of the backcasting approach is a clear future picture on what the transport system shall be like. It describes what targets shall be reached by the end of the project and how this target can be realized over a set period of time. The future picture of a transport system in itself is derived, defined and framed by a set of comprehensive development policies for a sustainable transportation (Litman, 2002; Litman, 2016; United Nations, 2016). This prospective development is made possible by the usage of the clearly pointed out action fields for the final conceptual design. It showed the discrepancies between the current and the prospected system but also indicated the disadvantages when current trends will not get addressed.

Never before was the backcasting approach, described by Geurs & van Wee, combined with Wegener & Fürst's feedback loop, which therefore opens up new possibilities for the prediction and evaluation of transport related measurements and further studies.

This research was able to show the given trend of increasing dependency on private motorization and its related decline in physical density and activities within the prefecture's settlements (Litman, 2002). It further illustrated the elderly declining willingness to drive as soon as age increases and their preferences to maintain their activities within close range around their place of stay (Szeto, et al., 2017).

In the end, the thesis was not able to derive a clear and comprehensive design for transport systems. It rather shows how current planning paradigms must and can be switched for a time with and when entire regions shrink or face ecological transformations.

This is also related to the lack of sufficient data. Most mobility and transport related data was available for the Sendai MEA. Other municipalities did either not provide data or it was insufficient. In addition, modal split estimations as well as the number of trips for the year of 2045 been based on extrapolations. In the context of the thesis, this value been used as an indicator for the potential systems increase in demand. The performed scenarios been performed in a qualitative way and therefore general.

The backcasting approach laid open a strong planning policy, which consequently reduces automobile dominance in traffic and transportation (Litman, 2002; Litman, 2002) and consequently increases and maintains a minimum population density in the build environment (Westphal, 2008). This is identified as the foundation for a naturally emerging sustainable transport system and settlement (Wegener & Fürst, 1999), which highly support the mobility of all and 'not just' the elderly (United Nations, 2016). In addition it increases the economic thrive of a region, based on higher cost efficiencies and mitigates climate change impacts by reducing greenhouse gasses and impervious surfaces. (Litman, 2016; SuM4All, 2017).

The realization of a balanced transport system which aims for a degree in motorization of *150 Veh./1,000 Inh.* and a population density *8,000 Inh./km²* within a period of 25 years (counted from 2020 to 2045) does not seem realistic, concerning the current political context within Miyagi prefecture.

The difference between the *projective (forecasting)* and the *prospective scenario (backcasting)* is so large, that an implementation in time can only be expected if public awareness would radically change. The realization of *150 Veh./1,000 Inh.* as target for the transport field implies a substantial change in travel behavioral and societal perspective as well as a tremendous change towards urban structure and distribution of activities in the Miyagi prefecture.

To ensure the mobility of all – *not just the elderly* – modern transportation planning must encounter more than just the application of demand-oriented and (potentially) automated transport modes. Since none of them seem to further encourage people to maintain or increase their activities in a sustainable way. And in turn, a shrinking and aging society, like the Miyagi prefecture, cannot only rely towards the expected benefits of automated demand-oriented transport services as the answer towards the current decline problems in peoples' mobility.

Focusing on the *human factor*, immobility can be related towards the obstacles every person is encountering during trips and their personal physical capability to master those, which definitely declines with age. Obstacles in traffic and transportation can be seen as oversized roads for private motorization and the absence of crossways, short green-times on traffic lights and indirect, detouring walkways or even the absence of such (ITDP, 2017).

Others are long waiting times, an unclear street design or long distances between activities (Szeto, et al., 2017). With a decrease in physical capability to master these obstacles in daily traffic and transport, the willingness to travel thus declines.

Immobility, as the utmost opposite of *universal access*, therefore is directly linked towards the physical implementation of transport infrastructures (*transport design*) and the size of settlements (*urban sprawl*).

The problem of immobile elderly can therefore be seen as the result of an inefficient transport and land use planning policy. One which does not include strategies for interconnected modes or dense and functionally mixed urban environments. As Westphal (2008) pointed out in her dissertation, the concept of compact settlement is not new, as well as transit-oriented developments or automobile free transportation. However, the implementation of such, is not easy since it requires a strong collaboration and interconnection between urban developers, transport planners and local decision makers.

Taking socio-economic challenges and climate change into consideration, transport planning should develop itself towards a discipline which is shaping the future, instead of just projecting it. The here presented methodology of backcasting, combined with an evaluation of planning effects, based on Wegener's 'feedback loop', is a big step into that direction. It provides an active approach on how our future shall look like and includes decision makers, planners and users into its process. It does provide an honest view of what needs to be done in order to reach the desired future image of a sustainable transport system for all.

The usage of backcasting however, comes with some limitations as well. One major aspect is that future developments are not be included in the desired future image and no steps towards their implementation is set. One major aspect is the technological development of autonomous vehicles, share-economy or natural disasters.

It is recommended to redo backcasting in a five-year interval in order to adjust the aimed planning towards the changing trends and other external factors in order to maintain the aimed development for sustainable transportation.

With respect to sustainable transportation planning, the Netherlands cannot learn much from Miyagi prefecture. In fact, Miyagi's transportation and land use is not adjusting towards the effects of aging and shrinkage on transportation and land use. With respect to the effects of urbanization and de-population however, Miyagi is of scientific interest, since it shows demographic developments and their impact on transport demand.

The Netherlands can learn that an uncoordinated shrinkage will first perforate settlements before they become disperse. Resulting in a strong financial load for basic services such as transportation and road maintenance. In turn, services will break away due to a lower demand and usage caused in a decreasing population and density. It can learn, that rural areas will get hit hard and first, followed by mid-sized cities and economic centers at last. A certain centralization towards the major cities can be assumed as potential development in the Netherlands.

According to the are Germany and Japan "*pioneers in demographic change*". De-population of the country side and an aging society are of no news for German science since the beginning of the 21st century, based on the developments of the countries east after its reunification, in 1990. The discussion of how to adjust transport and urban planning towards the trends of aging and shrinkage are far ahead of the once in Japan. With the result of Germanies *Urban Redevelopment East (Stadtumbau Ost)* program, which is an adequate measurement in place to reduce spatial occupation of settlements in a coordinated way. (Klingholz & Vogt, 2013)

Therefore, the Netherlands as well as Japan can learn from eastern Germany and its governmental approach to face shrinkage by a coordinated *dismantling* and *re-evaluation* of residential and industrial areas in order to maintain livability and provide sustainability.

CONCLUSION

The following conclusions are drawn from this research. The conclusions are presented in relation to the Research questions as introduced before:

How to design a regional transport system, which enhances the mobility of the elderly and can support a regions thrive in the face of uncertain future economic, social, and environmental shifts?

Mobility everyone – not just the elderly – is not a question related to transport technology – It is a question to spatial arrangement, design quality and the linkage of available modes.

It is not *just* a matter of transport engineering or related to the prospects of automated driving. Mobility is the result of modern skills of structuring space and the distribution of activities with the aim to bundle transport demands. Both with the aim to maximize urban and transport quality by minimizing energy consumption per capita.

Special requirements for improvement are seen in the functionality and appearance of streets and transport hubs and their degree in comfortable transfers.

With this in mind: A synergy between transport and urban planning which aims for a reduction in car dependency will *automatically* lead to a natural development of active and car independent elderly in a compact urban environment.

'Compact cities' is a concept for urban the environment which should stronger be included in sustainable traffic and transport planning. At the same time urban planning can include the knowledge about modal system characteristic of given (and potential) transport modes in order to provide better designs and concepts.

Sub Questions to answer the full width and depth of the main research question are:

1) *What development objectives shall be applied for regions facing depopulation and aging?*

Based on pollution decline and the increasing share of elderly in the remaining population, each transport system must adapt towards declining demands and change in transport demands.

The objective must be to guarantee the mobility needs of all age and population groups as well as to maintain, and even increase service quality for all modes and user groups while at the same time climate change impacts must be mitigated.

2) *What are goals and targets of sustainable transport systems facing aging and depopulation?*

A sustainable transport system aims for the balance of social, ecological and environmental aspects. In addition, it shall combine those three aspects into an

adequate design. Its overall goal is to avoid traffic, make people switch to walking and cycling for daily trip purposes and use public transportation for distances which active modes will not cover.

The design of a transport system shall meet all transport demands while being able to adjust towards them.

3) *What are the main characteristics of urbanization in relation to aging trends in Miyagi?*

Aging of society runs parallel to the emigration of educated working citizens towards the major cities. Which, in turn, accelerates the shrinking and aging process of a settlement. The shrinkage and aging society start in the country side. The decline in population of mid-size cities comes after. Economic centres and major cities, face those trends at last.

Without coordinating measurements, settlements will lose their population density. Public transport system will run with lower frequencies and therefore directly support private motorization as primary mode.

4) *How does the case of Miyagi relate to other similar cases around the world, as well as in recent history or near future?*

Japan and Germany are pioneers when it comes to an aging society. In General, all westernized developed countries will face aging and shrinkage. Similar demographic tendencies, comparable to Germany and Japan, can already be observed in the Dutch countryside, outside the Randstad area.

5) *What are the implications of these characteristics on the performance, sustainability, and resilience of a regional transport system?*

Especially the modes of public transportation suffer under population decline and de-densification. This is due to their system characteristics which mainly bundle transport demands. The decline in ridership makes them expensive to operate, which results in fewer services.

Due to the lack of adequate public services, the use and share of private motorization therefore barely changes or even increase despite population. Sustainable, or even resilient is a mono-modal oriented and car-depending society therefore not.

6) *Which design requirements and principles should guide the redesign for this specific Japanese case?*

The willingness to drive decreases with age. At the same time, the mobility of elderly increases when they have access to a sufficient walk and cycling infrastructure and close by facilities for daily necessities.

The principle of compact development shall guide the development, which defined by a coordinated shrinkage around bus stops and train stations under

the aim of minimum densities which justify high qualitative public transportation.

These requirements lead to design principles which favour walking and cycling as primary modes and demands the deconstruction of the car friendly infrastructure. Next to the expansion of public transportation, these principles also lead to the efficient interconnection of different modes.

7) *How can the insights gained from the Japanese case be generalized and applied to other countries/societies with comparable issues?*

The Miyagi case showed that shrinkage and aging in that region follows a similar pattern as it was observed in east Germany after 1990. The cause of shrinkage might differ, but its impact on settlements and transport systems is comparable. Both cases showed a decline in population density with parallel an increased share of elderly on the remaining population. Traffic and transport demand declines which causes collective modes to reduce service and in turn promotes private motorization.

From the point of view of a transport specialist, a defined minimum population density shall always be reassured around bus stops and train stations in order to economically justify high quality transport services. Which applies for facilities of daily use and social integration as well.

Towards sustainability, density of people and activities effects mode choice in a positive way. Walking and cycling is preferred for shorter distances.

Sustainable traffic and transport planning is therefore closely linked to the development of compact cities.

RECOMMENDATIONS

'Compact cities' is a concept for urban the environment which should stronger be included in traffic and transport planning. At the same time urban planning can include the knowledge about modal system characteristic of given (and potential) transport modes in order to provide better designs and concepts.

In this context, the following recommendations has been summarized for further research:

General Recommendation:

5. Backcasting as repetitive measurement to guide further development

Backcasting describes a desired picture of the future, based on the knowledge of today's identified problems. However, it is not possible to foresee future developments in technology, society, economy or ecology.

It is therefore recommended to include backcasting in the regions development planning process bases on a five-year interval. Aim is to evaluate if performed measures and concepts are still of importance to proceed or if new development is to include into the planning. All with the aim to reach the goal of sustainable transportation.

Recommendations for urbanism:

6. Minimum Population Densities for feasible Public Transportation in relation to the degree of motorization

Settlements of a high density show that inhabitants are more likely to walk, cycle and use collective public transportation.

With the goal to reduce the usage of private motorized vehicles and to increase the usage of attractive and reliable public transportation, the concept of minimum population densities around bus stops and train stations was introduced.

It is of interest, how the reduced degree in private motorization within a regions modal split is affecting the required minimum density of settlements, which is found to justify collective transport modes. It is expected, that an increased usage of public transportation could justifies lower minimum densities for settlements in order to validate the economic feasibility of them.

Foundation for this research can be the methodology applied by Westphal (2008). It shall evaluate further and be adjusted to include the variable of rising public transport demand.

7. Shrinking development concepts in the Japanese context as guidance for the compact city development

Contraction, fragmentation, perforation and dispersion are the four development concepts for shrinking cities which were elaborated for the east German context.

It is of interest, and therefore recommended to further investigate, how these four development concepts are applicable to the shrinking areas of Japan. This thesis pointed out similarities but did not further investigate them. Aim shall be to identify comparable as well as differential aspects.

A potential research could go forward in cooperation of with local universities and urbanism institutes. Based on literature research and their evaluation.

Recommendations for transport planning:

8. Sustainable street design in Japanese context as measurement to increase road safety and walkability

The Netherlands pioneers in traffic and road safety. In nearly no other country of the world are accidents and incidents as low as here. This is strongly related to the Dutch street design guidelines which aim to balance the needs of all traffic and transport participant and lead to the design concepts of 'sustainable roads'.

It is of interest, how the Dutch street design principles could be brought into the Japanese context. Especially the concepts of sustainable roads and road hierarchy in japan should be investigated. The concept of shared space is of interest as design for narrow side streets in dense urban environment (i.e. Yokohama).

A potential research could go forward in cooperation of with local universities and transport institutions. Knowledge can be shared and applied on suitable road section in Japan. The impact on traffic safety and acceptance can be investigated by observation.

9. Design guidelines for the interaction and combination of collective and non-motorized transport modes

The quality and thus acceptances of multi-modal trips is highly deepening on the number and experience of transfers.

With the aim to strengthen multi-modal trips, it is of importance on how to design sufficient infrastructural networks and transfer hubs for collective and active modes.

It is therefore of interest, to further investigate the user experience of transfers with the aim to better it. It is expected that, the quality of stay around points of transfers positively impact the experience to transfer. New concepts, such as shops, institutions or just public bookshelves which are integrated in bus stops could strengthen collective transportation and increases the acceptance to transfers. However, sufficient public transportation offers frequencies, which result in short waiting times.

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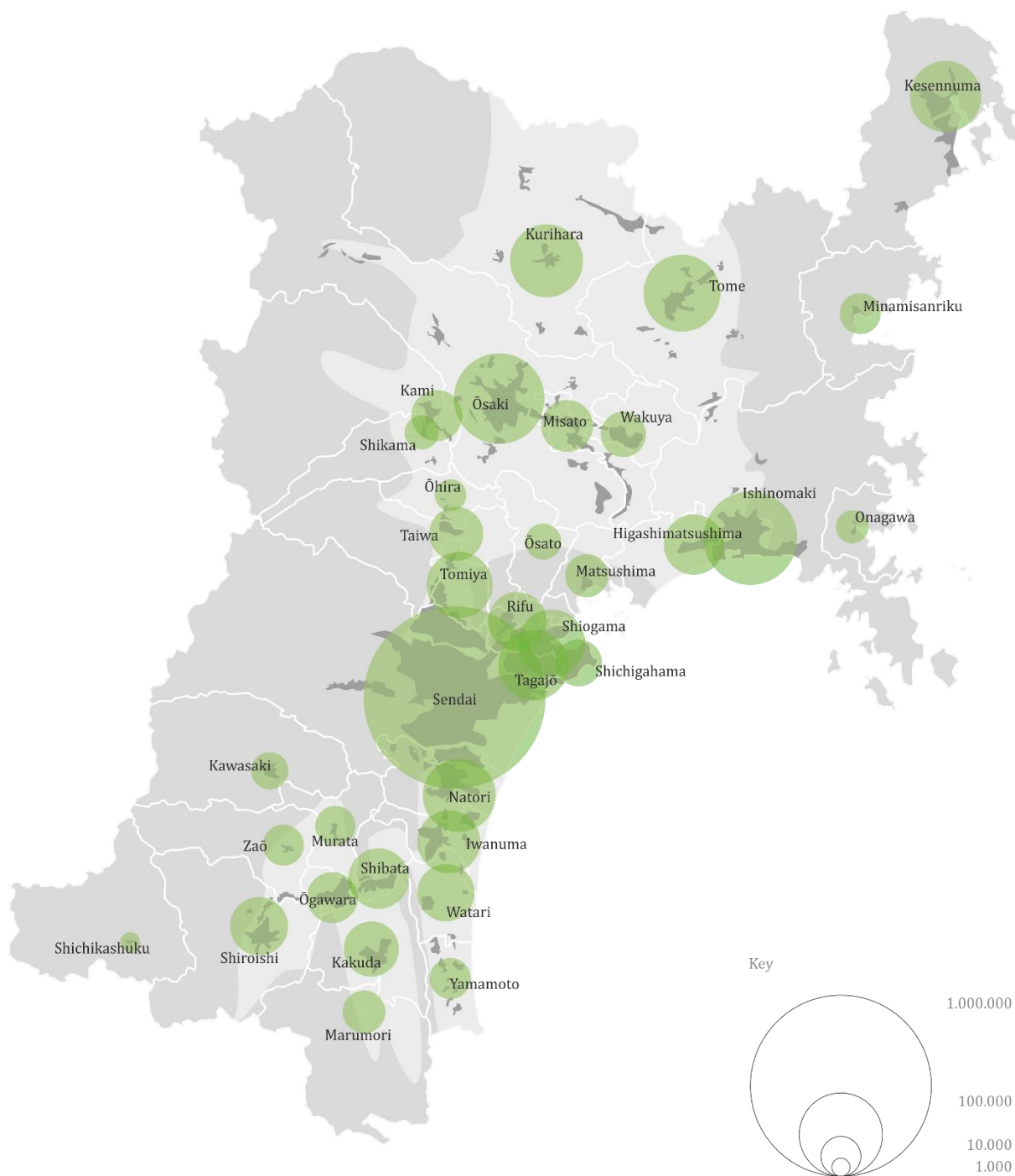
APPENDIX 01 | SUSTAINABLE TRANSPORT OBJECTIVES, PERFORMANCE INDICATORS AND TARGETS

Sustainability Objectives	Objective Group	Performance Indicators	Target
I. Economic			
Transport system efficiency.	EF	Performance in relation to Capacity	Increase ↗
		Travel Speed	Increase ↗
		Reliability - Congestion reduction (Private Vehicles)	Decrease ↘
		Reliability - Punctuality and Constant Speed (Public Transportation)	Increase ↗
Transport system integration.	UA	Measurements for combined mobility	Increase ↗
Maximize accessibility.	UA	Number of people in catchment area of Main Road or Public Transport access points	Increase ↗
		Temporal access towards Transportation	Increase ↗
Efficient pricing and incentives.	EF	Efficient pricing (road, parking, insurance, fuel, etc.).	Increase ↗
		Efficient prioritization of facilities (roads and parking).	Increase ↗
Economic and business development	UA	Access to education and employment opportunities.	Increase ↗
		Support for local industries.	Increase ↗
Minimize energy costs, particularly petroleum imports.	EF	Per capita transport / mobility energy consumption	Decrease ↘
All residents can afford access to basic (essential) services and activities.	UA	Availability and quality of affordable modes (walking, cycling, ridesharing and public transport).	Increase ↗
Efficient operations and asset management maximizes cost efficiency.	EF	Service quality	Increase ↗
		Operational costs	Decrease ↘
		Need for Investments	Decrease ↘
		Operational Costs per capita	Decrease ↘
II. Social			
Transport system accommodates all users, including those with disabilities, low incomes, and other constraints.	UA	Transport system diversity.	Increase ↗
		Portion of destinations accessible by people with disabilities and low incomes.	Increase ↗
Minimize risk of crashes and assaults	SA	Per capita traffic casualty (injury and death) rates.	Decrease ↘
		Traveler crime and assault rates	Decrease ↘
Support physical fitness and health	SA	Portion of travel by walking and cycling	Increase ↗
Help create inclusive and attractive communities.	UA	Land use mix.	Increase ↗
Support community cohesion.	UA	Walkability and bikeability / public places	Increase ↗
		Quality of road and street environments.	Increase ↗
Respect and protect cultural heritage.	UA	Preservation of cultural resources and traditions.	Increase ↗
Support cultural activities	UA	Responsiveness to traditional communities.	Increase ↗

Sustainability Objectives	Objective Group	Performance Indicators	Target
III. Environmental			
Reduce global warming emissions	GM	Per capita emissions of global air pollutants (CO ₂ , CFCs, CH ₄ , etc.)	Decrease ↘
Mitigate climate change impacts	GM	Share of Vehicles with low exhaustion of emissions / car-free households	Increase ↗
Reduce air pollution emissions	GM	Per capita emissions of local air pollutants (PM, VOCs, NO _x , CO, etc.)	Decrease ↘
Reduce exposure to harmful pollutants.	GM	Exposure	Decrease ↘
Minimize traffic noise exposure	GM	Traffic noise levels / exposure	Decrease ↘
Minimize water pollution.	GM	Per capita fuel consumption.	Decrease ↘
Minimize impervious surface area	GM	Management of used oil, leaks and storm water.	Increase ↗
		Per capita impervious surface area.	Decrease ↘
Minimize transport facility land use.	EF	Land devoted to transport facilities.	Decrease ↘
Encourage compact development.	EF	Support for smart growth development.	Increase ↗
		Share of Traffic and Transport space on Settlement area	Decrease ↘
		Population density	Increase ↗
		Traffic and Transport Area per Transport System	Decrease ↘
		Public Transport accessed Settlements	Increase ↗
Preserve high quality habitat.	GM	Policies to protect high value farmlands and habitat.	Increase ↗

(source: own illustration based on Litman, 2016 and extended with SuM4All, 2017)

APPENDIX 02 | POPULATION [INH.] – GEOGRAPHIC DISTRIBUTION IN 2015

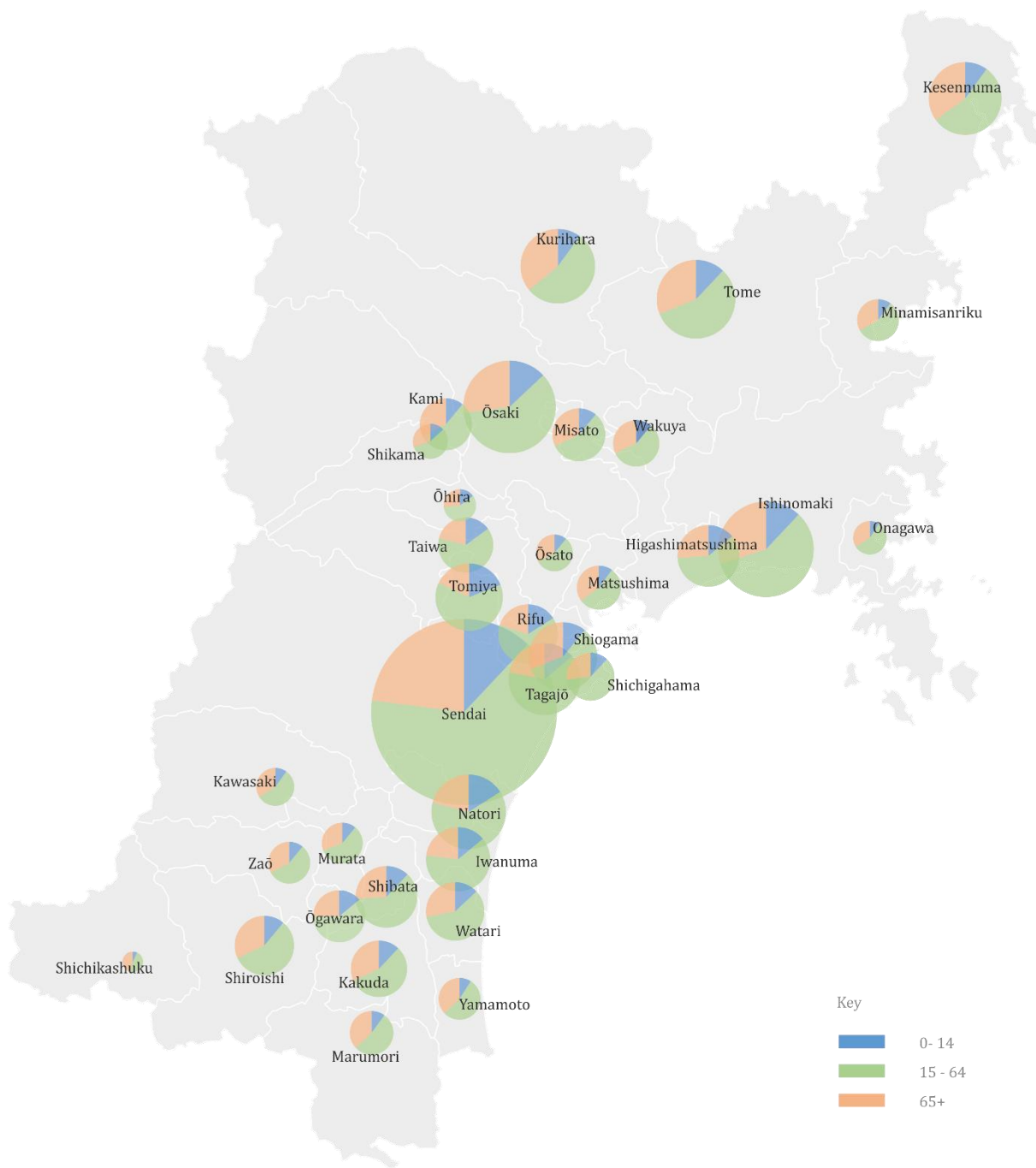


(source: own illustration, based on MIC, 2017a; MIC 2017b and eCitizen, 2018)

Agglomeration	Population		Age group				
	Total	0-14		15-65		65+	
Sendai MEA	1,581,799	203,706	13%	1,010,532	64%	367,561	23%
Ishinomaki Aggl.	196,232	23,637	12%	115,141	59%	57,454	29%
Ōsaki Aggl.	203,548	24,928	12%	119,046	58%	59,574	29%
Tome/Kurihara	149,345	16,661	11%	82,964	56%	49,720	33%

(source: own illustration, based on MIC, 2017a; MIC 2017b and eCitizen, 2018)

APPENDIX 03 | POPULATION [INH.] AND AGE GROUPS – GEOGRAPHIC DISTRIBUTION 2015

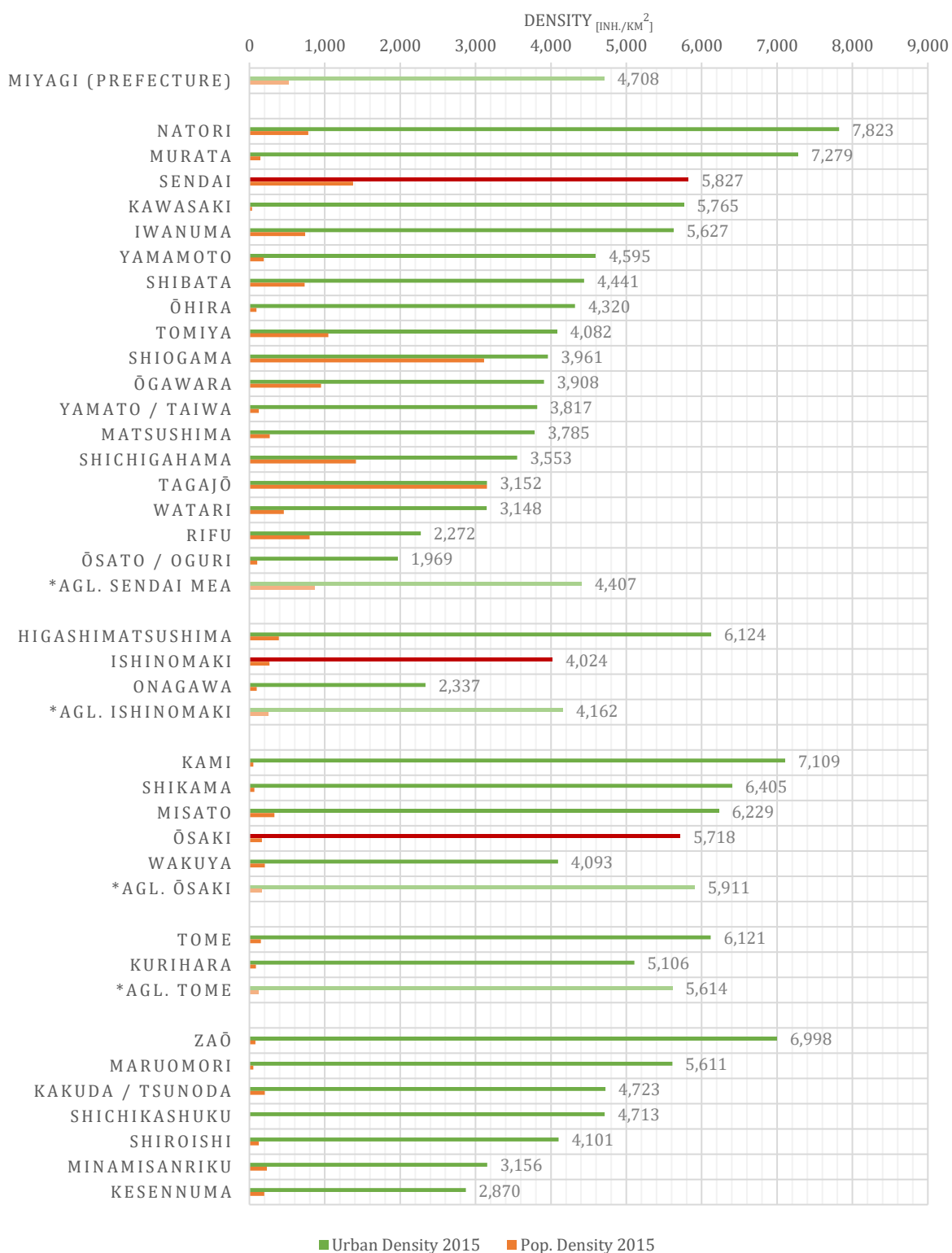


(source: own illustration, based on MIC, 2017a; MIC 2017b and eCitizen, 2018)

APPENDIX 04 | POPULATION [INH.] – 2015

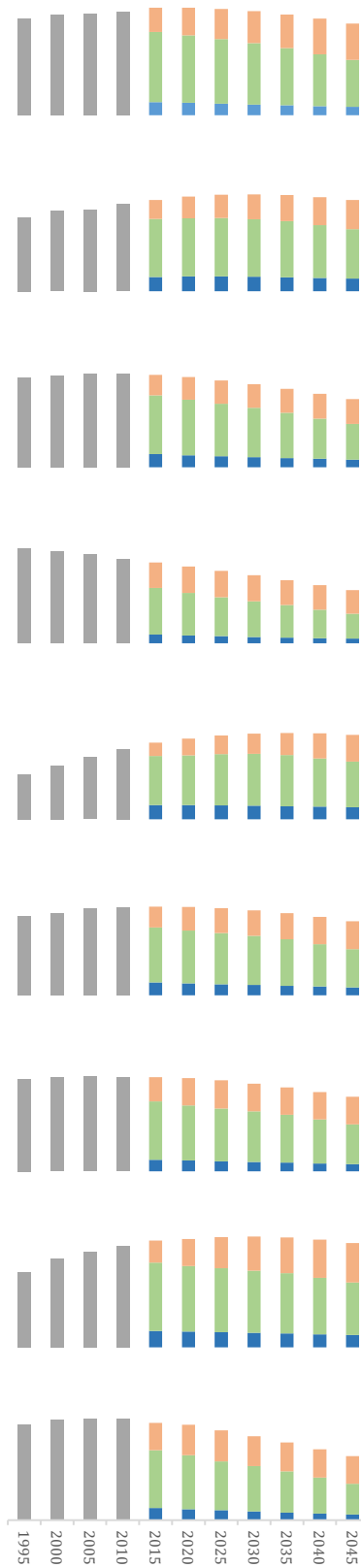


(source: own illustration, based on MIC, 2017a; MIC 2017b and eCitizen, 2018)

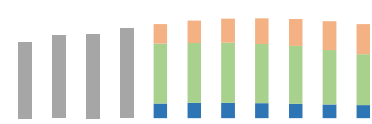
APPENDIX 05 | POPULATION AND SETTLEMENT DENSITY [INH./KM²] - 2015

(source: own illustration, based on MIC, 2017a; MIC 2017b and eCitizen, 2018)

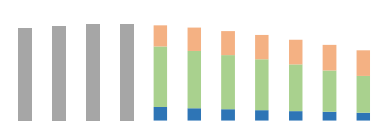
APPENDIX 06 | POPULATION DEVELOPMENT



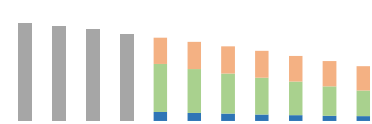
Sendai
 2035: -12%
 2045: -22%



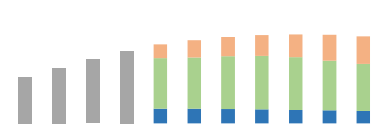
Natori
 2035: +5%
 2045: ±0%



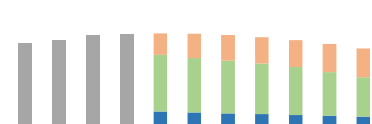
Tagajō
 2035: -15%
 2045: -26%



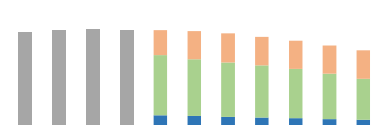
Shiogama
 2035: -22%
 2045: -34%



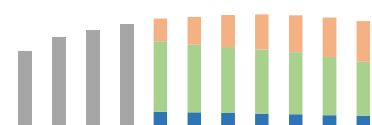
Tomiya
 2035: +13%
 2045: +10%



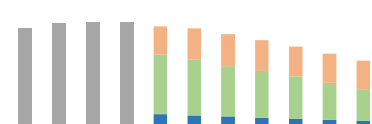
Iwanuma
 2035: -7%
 2045: -16%



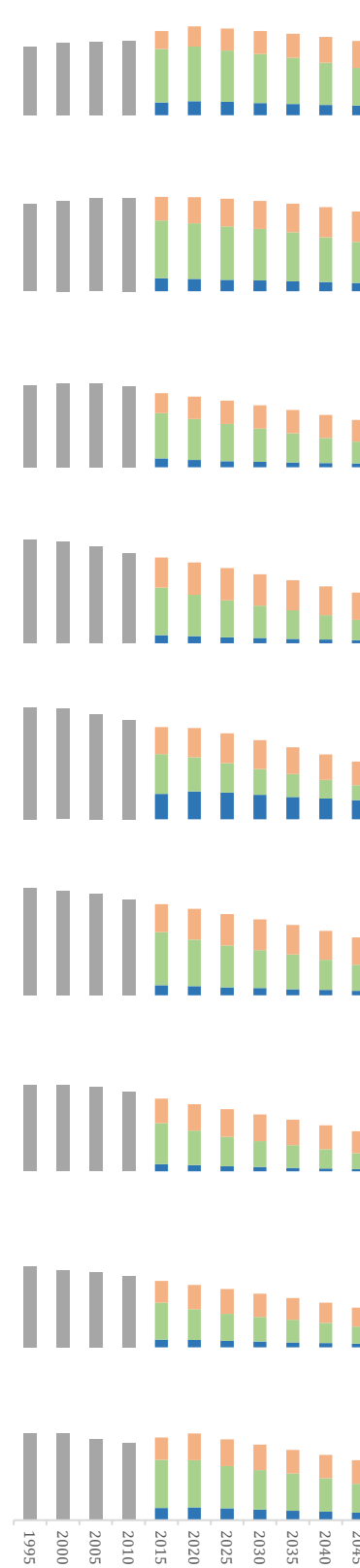
Shibata
 2035: -11%
 2045: -21%



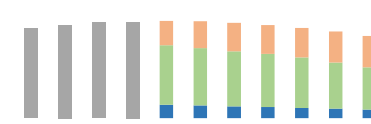
Rifu
 2035: +3%
 2045: -2%



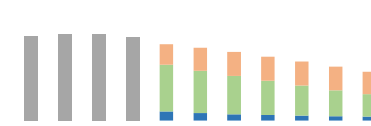
Watari
 2035: -20%
 2045: -34%



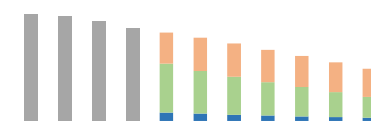
Yamato
 2035: -13%
 2045: -12%



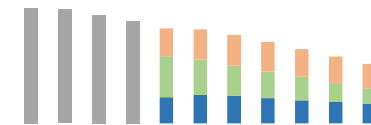
Ogawara
 2035: -7%
 2045: -15%



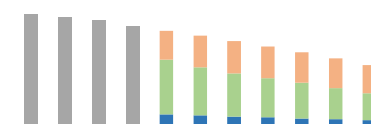
Shichigahama
 2035: -23%
 2045: -36%



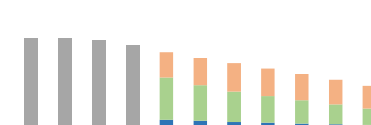
Matsushima
 2035: -26%
 2045: -41%



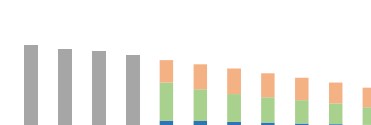
Yamamoto
 2035: -28%
 2045: -45%



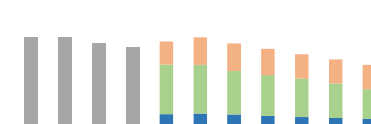
Murata
 2035: -23%
 2045: -37%



Kawasaki
 2035: -29%
 2045: -45%

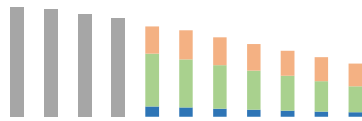


Ōsato
 2035: -26%
 2045: -40%

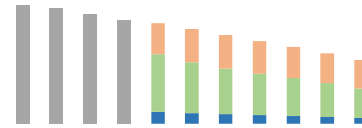


Ōhira
 2035: -15%
 2045: -27%

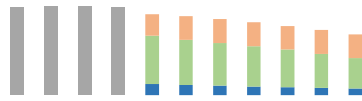
(source: own illustration, based on MIC, 2017a; MIC 2017b and eCitizen, 2018)



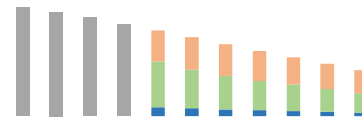
Ishinomaki
2035: -27%
2045: -41%



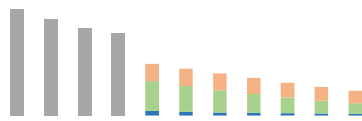
Tome
2035: -24%
2045: -36%



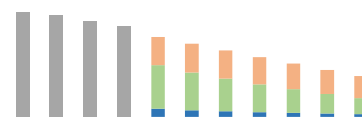
Higashi-matsushima
2035: -14%
2045: -25%



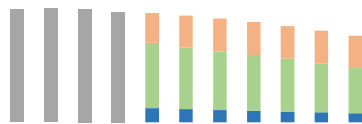
Kurihara
2035: -31%
2045: -46%



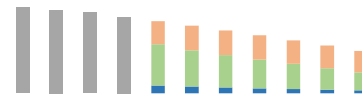
Onagawa
2035: -37%
2045: -52%



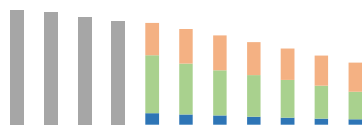
Kesennuma
2035: -33%
2045: -49%



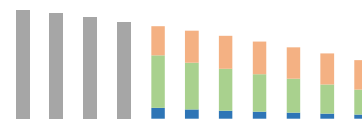
Ōsaki
2035: -12%
2045: -27%



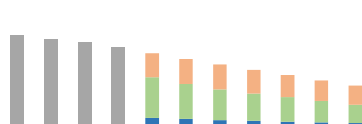
Shiroishi
2035: -27%
2045: -41%



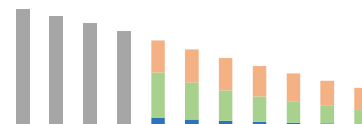
Misato
2035: -25%
2045: -39%



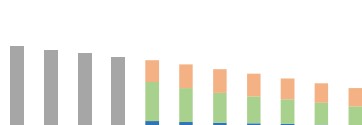
Kakuda
2035: -23%
2045: -37%



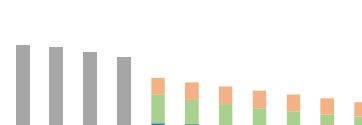
Kami
2035: -30%
2045: -45%



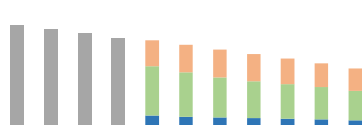
Maruomori
2035: -39%
2045: -55%



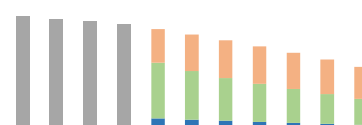
Wakuya
2035: -27%
2045: -41%



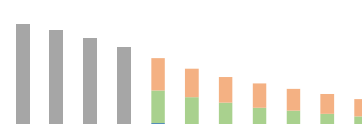
Minami-sanriku
2035: -33%
2045: -48%



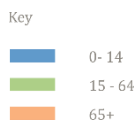
Shikama
2035: -21%
2045: -33%



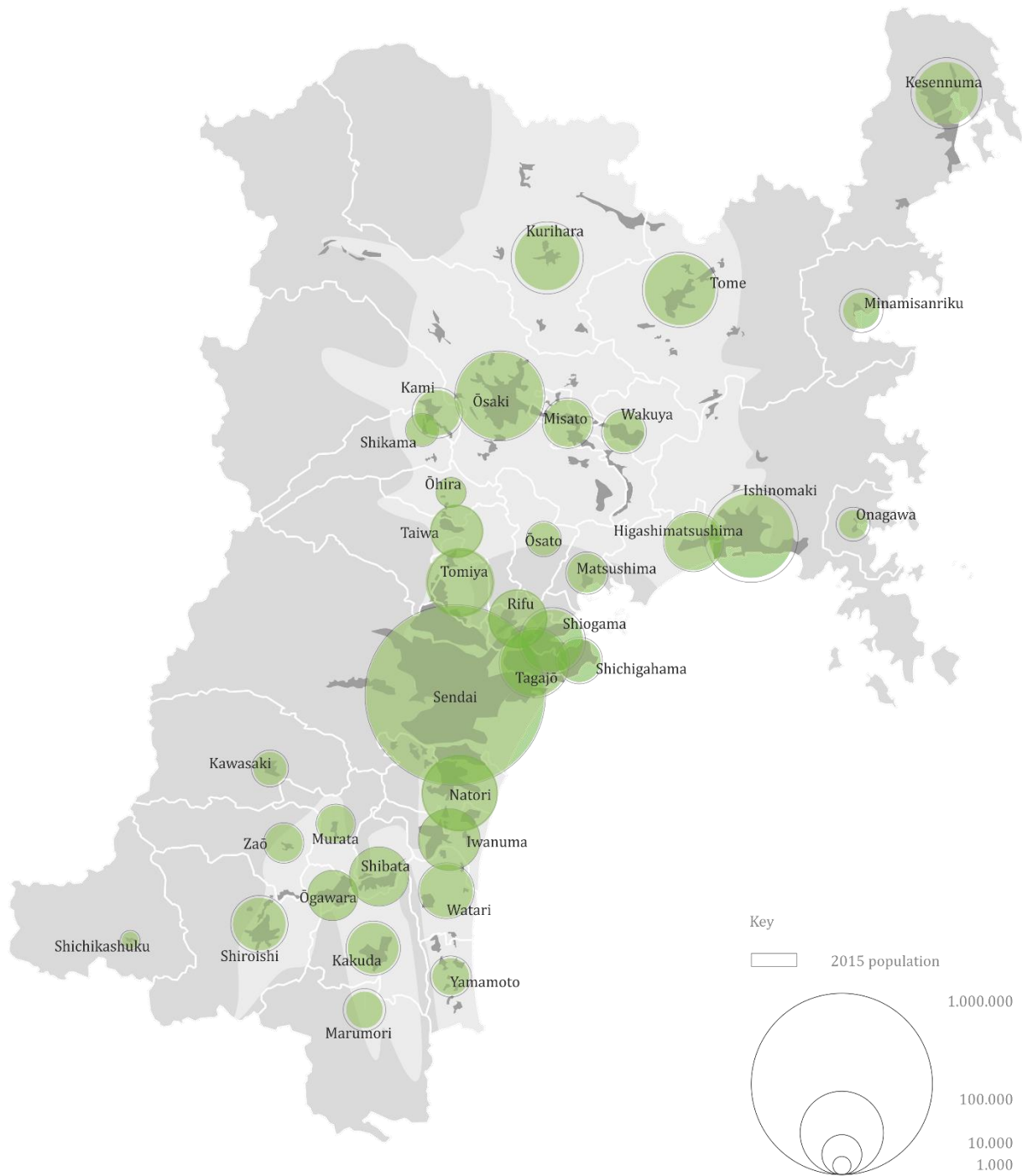
Zaō
2035: -23%
2045: -37%



Shichikashuku
2035: -44%
2045: -58%

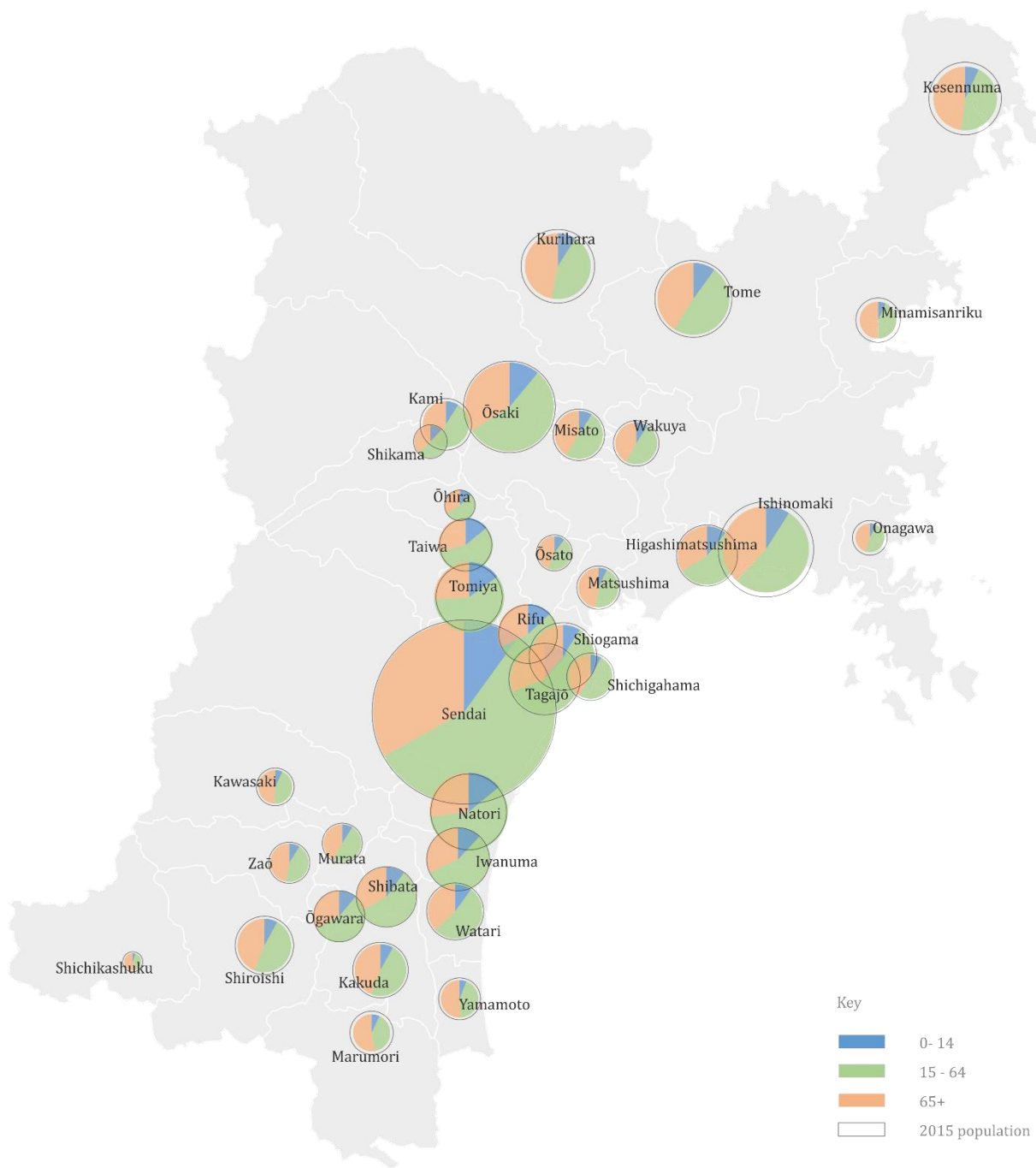


APPENDIX 07 | POPULATION [INH.] – GEOGRAPHIC DISTRIBUTION 2035



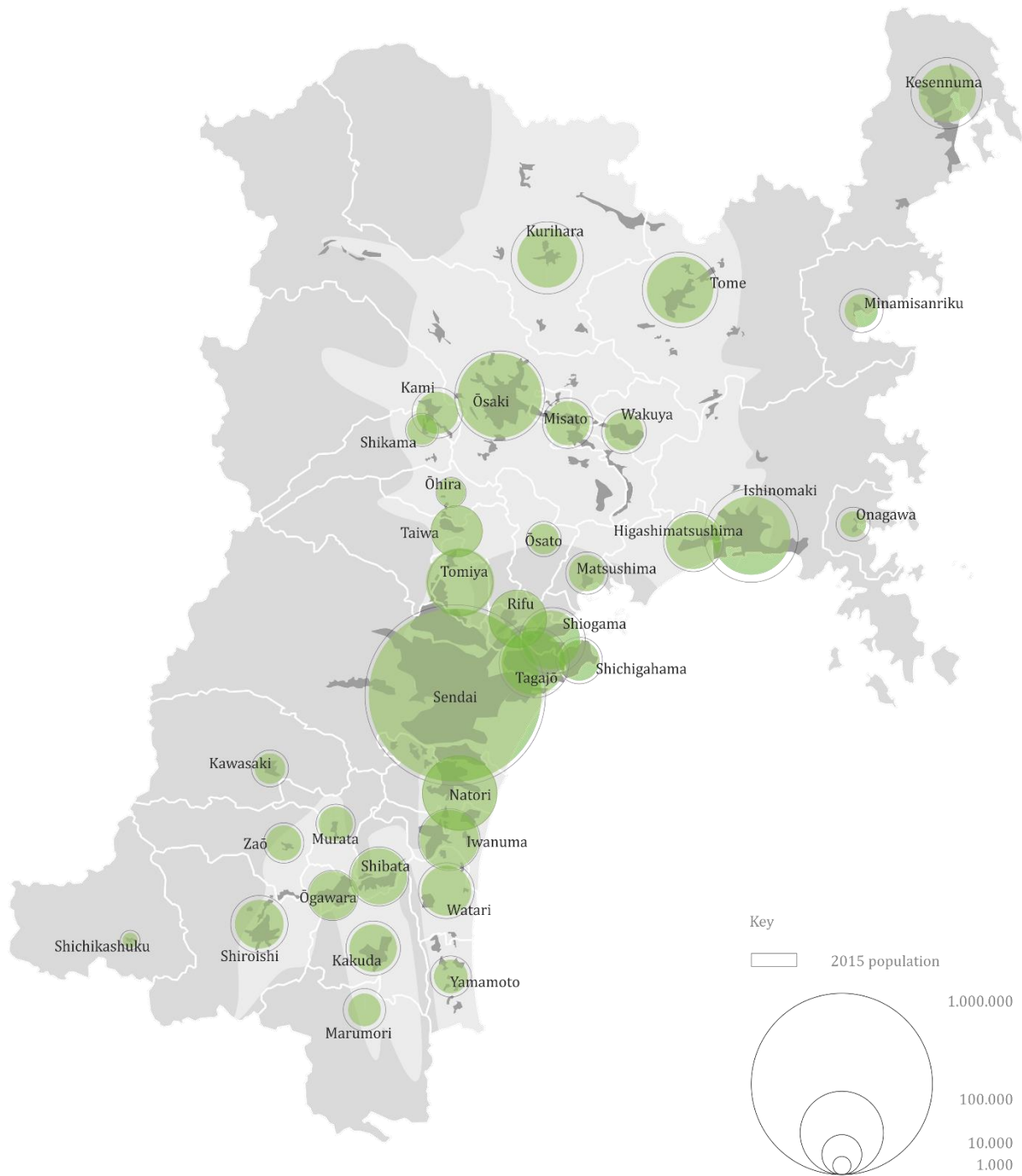
(source: own illustration, based on MIC, 2017a; MIC 2017b and eCitizen, 2018)

APPENDIX 08 | POPULATION [INH.] AND AGE GROUPS – GEOGRAPHIC DISTRIBUTION 2035



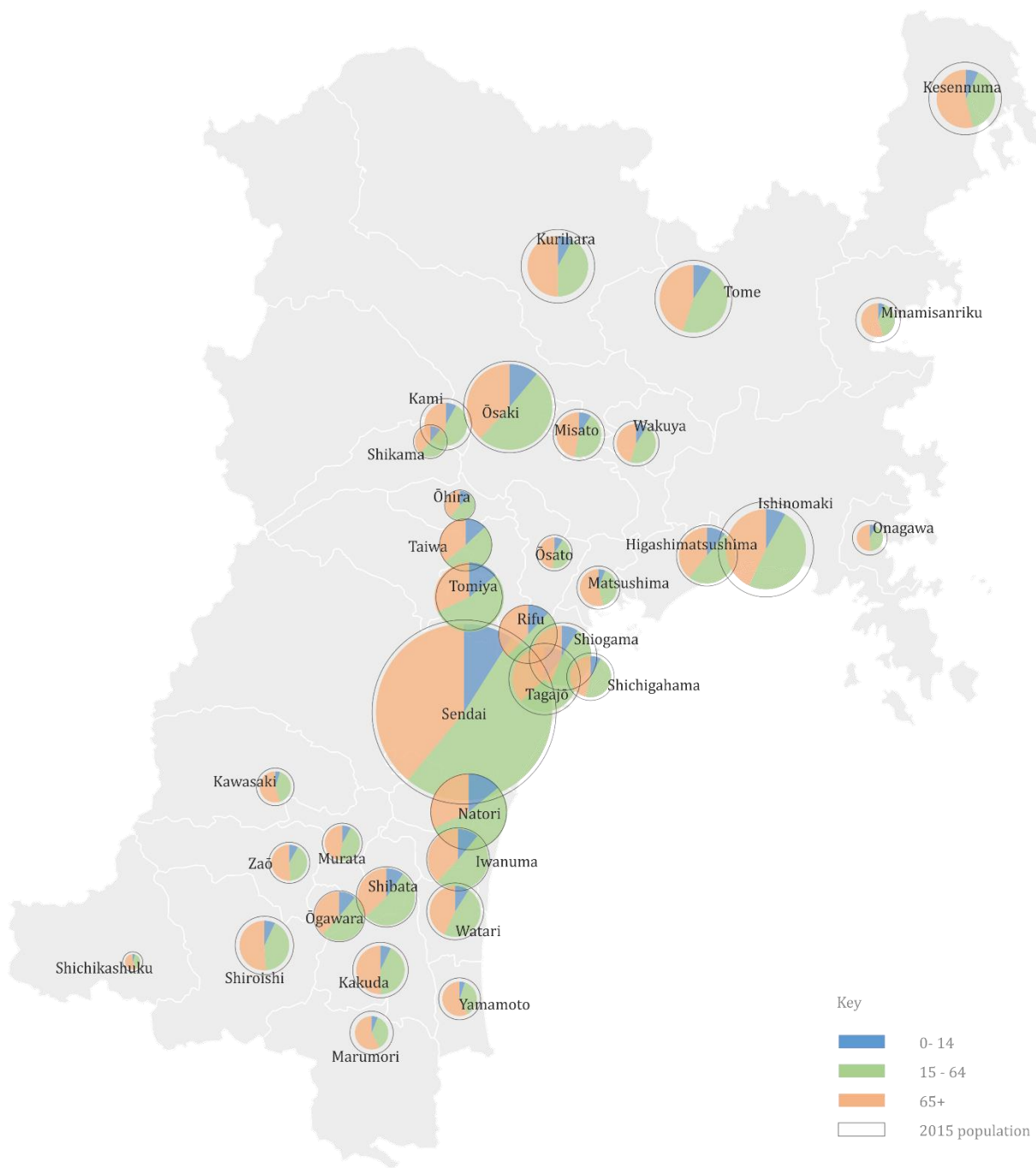
(source: own illustration, based on MIC, 2017a; MIC 2017b and eCitizen, 2018)

APPENDIX 09 | POPULATION [INH.] – GEOGRAPHIC DISTRIBUTION 2045



(source: own illustration, based on MIC, 2017a; MIC 2017b and eCitizen, 2018)

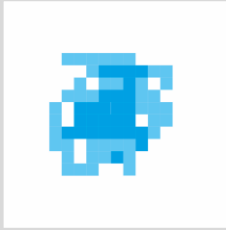
APPENDIX 10 | POPULATION [INH.] AND AGE GROUPS – GEOGRAPHIC DISTRIBUTION 2045



(source: own illustration, based on MIC, 2017a; MIC 2017b and eCitizen, 2018)

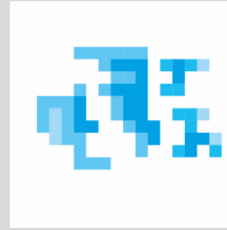
APPENDIX 11 | GUIDING CONCEPTS – SHRINKING CITIES

Contraction



Corresponds to the ideal of compact cities, the concept of *contraction* strive for maintaining a viable urban core, for a consistent decommission from outside to inside and the preservation of high dense inner-city centers. In addition, the aim is to create a clear border with the landscape, sustainable urban structures and a high quality of life.

Fragmentation



While the goal of *contraction* aims at a consistent reduction of a cities body to a viable core, the *fragmentation* on the one hand focuses on strengthening the inner-city center, on the other to maintain the function of the cities sub-centers. This results in a city body consisting of viable settlement nuclei, which – similar to islands or plaques – are located in a green urban fabric.

Dispersion

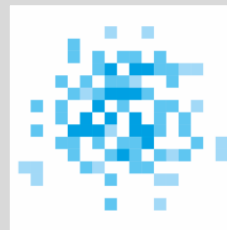


As a description of the state, the *dispersion* under shrinkage represents a loosening and expansion of the settlement structures in two ways:

- *At first, the intensity of use and density in the settlement decreases*
- *At second, the settlement is expanding at the same time by the resettlement of low-density uses along the edges of the settlement.*

Guiding principles of the development of disperse settlement argue that, instead of applying a planning control to stabilize cores of higher density, the use and design potentials of reduced densities should be explored, and field of action should be encouraged.

Perforation

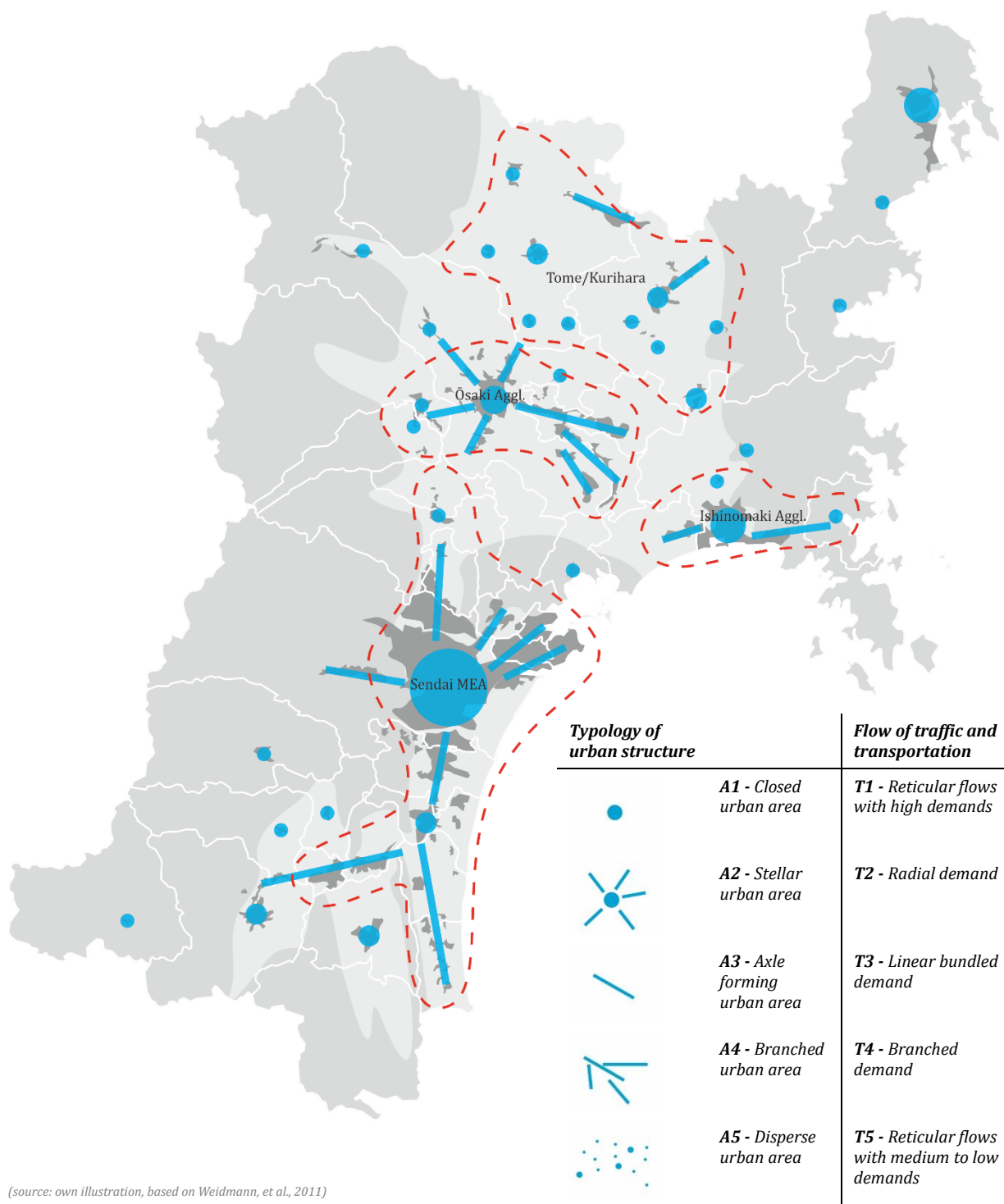


The *perforated* city is first of all a description of state. As part of the discussion however, goals were developed on how to deal with this type of shrinking city.

As a description of state, the perforation represents a process of uncontrolled and uneven decommission of urban structures due to population and demand reductions. In the course of an urban planning succession that can no longer be controlled, cities are created whose original build up environment is 'perforated'. The perforated city is characterized by the fact that growth and shrinkage often occur in small parts next to each other. There is an immediate proximity of robust and subsistent nuclei and stagnant or even abandoned areas with poor development prospects.

(Source: own illustration and translated from Westphal, 2008)

APPENDIX 12 | URBAN TYPOLOGIES – MIYAGI



(source: own illustration, based on Weidmann, et al., 2011)

Urban Typologies per Agglomeration:

Agglomeration	Structure	Av. Density in Settlements [Inh./km ²]	Av. Population Density [Inh./km ²]
Sendai MEA	A2 – Stellar	4,407	391
Ishinomaki Aggl.	A3 – Axle	4,162	120
Ōsaki Aggl.	A2 – Stellar & A4 – Branched	5,910	164
Tome/Kurihara	A5 – Disperse	5,614	251

(source: own illustration, based on Weidmann, et al., 2011 and eCitizen, 2018)

APPENDIX 13 | MODAL SHIFT CALCULATION

The German Environment Agency (*Umweltbundesamt – UBA*) indicated their high ambition to reduce car ownership towards of **150 Veh./1,000 Inh.** in German cities. Within this thesis, this particular value is used as a major target for the degree of private motorization for Sendai and the Miyagi prefecture as well and shall be reached the latest by 2045. (BAU, 2017)

This section addresses this ambitious target and derives its impact towards the prefectures modal split and its related increase and decrease in service demand. Especially towards collective modes of public transport and active modes. This is done by a set of calculative steps which are further explained in the upcoming paragraphs.

the **1st step**, assumes, that the degree of private motorization is directly linked to automobile usage. The only degree of motorization and automobile mode share is found for the *Sendai MEA*. Within this estimation, both are set in relation with each other and put into a linear extrapolation towards the prospected degree of *150 Veh./1,000 Inh.* [1]. By rearranging equation [1] towards the to estimate modal share [2] will result in the prospected automobile usage of the aimed year of 2045 [3].

$$\frac{53,5\% \text{ Modal share}}{\frac{570 \text{ Veh.}}{1,000 \text{ Inh.}}} = \frac{x\% \text{ Modal share}}{\frac{150 \text{ Veh.}}{1,000 \text{ Inh.}}} \quad [1]$$

$$x\% \text{ Modal share} = \frac{53,5\% \times \frac{150 \text{ Veh.}}{1,000 \text{ Inh.}}}{\frac{570 \text{ Veh.}}{1,000 \text{ Inh.}}} \quad [2]$$

$$x\% \text{ Modal share} = 14,1\% \quad [3]$$

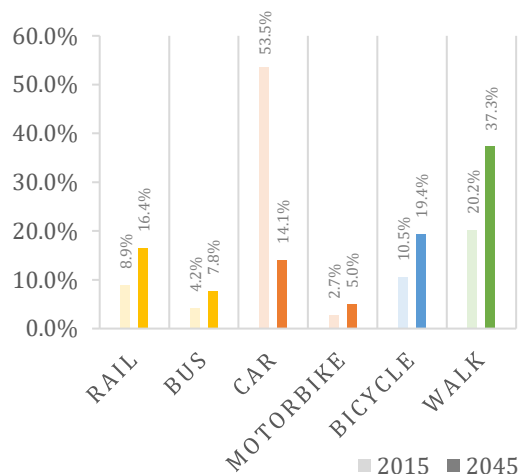
According to the assumptions and estimation above, the usage of the automobile would reduce of about (53,5% - 14,1% =) 39,4%.

The **2nd step**, is based on the assumption that mode choice for the remaining available transport modes will not change and that therefore former automobile users will choose similar. It is for this assumption, that the 39,4% got naturalized and proportion in accordance towards the remaining modes available.

This estimation was applied towards the modal split of the *Sendai MEA* and its outcome is presented in Appendix 13 A.

A sufficient data set about the number of trips and related transport mode as well as the degree of private motorization for the other three identified agglomerations (Appendix 12) was not accessible. A sufficient estimation of the modal split and its potential development for the areas outside of the *Sendai MEA* therefore was not possible to conduct.

APPENDIX 13 A| MODAL SPLIT – SENDAI MEA 2045



(Source: own estimation, based on Dimmer, 2017)

Result of this estimation, is that the usage of each transport mode apart of the private automobile nearly doubles in demand.

The share of railway uses increases from 8.9% towards 16,4% which relates to an increase by 84.3%. The usage of busses increases from 4.2% to 7.8%, which is an increase of 85.7%. The share of walk and cycling would increase to a combined share of 56,7%, more than half of all trips in the *Sendai MEA* would be done by active modes.

However, since the number of citizens decline and travel patterns change, the actual number of trips won't increase as much as the estimated modal split. The actual number of trips is not known, and therefore cannot be related with the modal split. What is known is the number of citizens in 2015 and (as given by Appendix 06) for 2045.

The **3rd step**, therefore relates the modal share and population number of the *Sendai MEA* with each other for the year 2015 and 2045. The ratio is estimated out of the product of *MEA* citizens and each modal share in order to derive the increase in demand for 2045. This increase (or decrease) in demand is listed in Appendix 13 B and shall be understand as the potential maximum since ageing reduces the trip rate which was not included into this calculation.

APPENDIX 13 B| TRIP INCREASE

Mode	Maximum increase in demand
Rail	+ 55.1%
Bus	+ 56.3%
Car	- 77.8%
Motorbike	+ 55.9%
Bike	+ 49.8%
Walk	+ 55.4%

(Source: own estimation)

APPENDIX 14 | DENSITY & AREA IMPACT

The Japanese *Ministry of Land, Infrastructure, Transport and Tourism (MLIT)* investigated the concept of low-carbon cities and, as a final step, modeled the measurements expected impact on the Sendai MEA. The studies ambitious targets towards population density are listed below: (MLIT, 2011)

City center	7,800	to	12,000	Inh./km ²
Hub	5,000	to	8,000	Inh./km ²
Core traffic point	4,600	to	6,000	Inh./km ²
Outskirts	4,000	to	2,000	Inh./km ²
Suburbs	330	to	900	Inh./km ²

The simulation showed, that in total 24% of the current co2 emission can be reduced. In detail, compact city planning, makes approximately 12% of the saved emissions. Effects on traffic make 4.9% of the reduced pollutions. 7.1% are related to the decline in population size. (MLIT, 2011)

Within this estimation, and with respect to the work of Westphal (2008), the target of *8,000 Inh./km²* is used as an indicator for the proposed densification around stops and stations until 2045.

The aim of this section is twofold:

First aim is to estimate the effect of depopulation on population density in the build-up environment, assuming no policies and measurements will be embedded in order to face shrinkage. This estimation is related towards the projective scenario, where the effects of the given trends where described.

Second aim is to identify the effects of densification on the ground occupation. For that case an average density of at least *8,000 Inh./km²* is assumed as the goal for each settlement in the Miyagi Prefecture. This estimation is related towards the prospective scenario, where the effects of newly embedded policies and measurements should be estimated.

1st Step: Density development in the projective scenario:

It is assumed, that the area of a settlement, as identified and indicated above will remain stable over the upcoming 20 to 30 years.

Therefore, the estimated population (*Backcasting Step 4*) of the build environment for the years 2035 and 2045, of each settlement divided by the settlements area (see chapter 3).

The results are shown in Appendix 14 A.

Within the Miyagi prefecture, the only growing municipalities are *Natori* and *Rifu*, both located in the Sendai MEA and directly bordering Sendai. However, this growth is expected to last until 2035. Until 2045 both municipalities are expected to shrink as well.

Sendai on the other hand is expected to decrease in population size already until 2035. A factor which can also be seen in the estimated population densities for the build environment.

In combination with the other municipalities it can be concluded, that the population density of the build environment within the Sendai MEA is further thinning out. Sendai MEA will reduce in density of about 7,0% until 2035 and 15,8% until 2045. The agglomeration of Ishinomaki will even decrease in population density by 24.7% until 2035 and 38.2% by 2045. By 2035, Ōsaki is expected to be the 2nd largest city of Miyagi, its agglomeration area will reduce by 17% 2035 and 27.7% by 2045. Harder will tome and Kurihara face de-population and a decline in density. Until 2035, this agglomeration will lose 27.2% and 41.0% until 2045.

2nd Step: Area Development in the prospective scenario:

The targeted minimum density of *8,000 Inh./km²* is divided by the number of expected inhabitants of each settlement of the year 2035 and 2045, As a result, the reduced area in percentage. The results are shown in Appendix 14 B.

Until 2035 huge reduction of space, but an even faster reduction from 2035 to 2045. Within 20 years, from 2015 to 2035, a reduction of occupied land can be achieved of **-12.3%**. Further within ten years, from 2035 to 2045, a further reduction of **-10.2%**, can be achieved for the Miyagi prefecture.

In total, **247.46 km²** of buildup area could be de-constructed and developed to a green environment as pointed out in subchapter 5.7 (p. 43).

In order to visualize the dimension of the reduced land occupation a simple comparison is conducted: The estimated re-naturalized area of 247.46 km² is nearly as big as the entire municipality area of Amsterdam (219.32 km²) and Haarlem (32.09 km²) combined.

APPENDIX 14 A | DENSITY DEVELOPMENT – PROJECTIVE DEVELOPMENT

Density is referring to population density in the build-up environment.

The delta indicates the change of density, towards the base year of 2015.

	2015		2035			2045		
	Population [inh]	Density [inh./km ²]	Population [inh]	Density [inh./km ²]	Δ [%]	Population [inh]	Density [inh./km ²]	Δ [%]
Miyagi (Prefecture)	2,333,899	4,928	2,046,219	4,321	-12.3%	1,809,021	3,820	-22.5%
Sendai	1,082,159	5,827	1,015,478	5,468	-6.2%	922,655	4,968	-14.7%
Natori	76,668	7,823	80,769	8,242	5.3%	76,595	7,816	-0.1%
Tagajō	62,096	3,152	52,741	2,677	-15.1%	45,821	2,326	-26.2%
Shiogama	54,187	3,961	42,409	3,100	-21.7%	35,625	2,604	-34.3%
Iwanuma	44,678	5,627	41,369	5,210	-7.4%	37,355	4,705	-16.4%
Rifu	35,835	2,272	36,959	2,344	3.1%	35,037	2,222	-2.2%
Watari	33,589	3,148	26,834	2,515	-20.1%	22,154	2,076	-34.0%
Taiwa	28,244	3,817	27,399	3,703	-3.0%	24,968	3,374	-11.6%
Yamamoto	12,315	4,595	8,854	3,304	-28.1%	6,806	2,540	-44.7%
Ōsato / Oguri	8,370	1,969	6,224	1,464	-25.6%	5,018	1,181	-40.0%
Tomiya	51,591	4,082	58,051	4,593	12.5%	56,822	4,495	10.1%
Shibata	39,525	4,441	35,201	3,955	-10.9%	31,280	3,515	-20.9%
Ōgawara	23,798	3,908	22,079	3,625	-7.2%	20,110	3,302	-15.5%
Shichigahama	18,652	3,553	14,426	2,748	-22.7%	11,906	2,268	-36.2%
Matsushima	14,421	3,785	10,606	2,784	-26.5%	8,496	2,230	-41.1%
Murata	11,501	7,279	8,857	5,606	-23.0%	7,293	4,616	-36.6%
Kawasaki	9,167	5,765	6,497	4,086	-29.1%	5,069	3,188	-44.7%
Ōhira	5,703	4,320	4,855	3,678	-14.9%	4,148	3,142	-27.3%
Agglomeration	1,612,499	5,058	1,499,608	4,704	-7.0%	1,357,158	4,257	-15.8%
Ishinomaki	147,214	4,024	107,494	2,939	-27.0%	86,697	2,370	-41.1%
Higashimatsushima	39,503	6,124	33,841	5,247	-14.3%	29,655	4,598	-24.9%
Onagawa	6,334	2,337	4,022	1,484	-36.5%	3,025	1,116	-52.2%
Agglomeration	193,051	4,221	145,357	3,178	-24.7%	119,377	2,610	-38.2%
Ōsaki	133,391	5,718	117,643	5,043	-11.8%	105,734	4,532	-20.7%
Wakuya	16,701	4,093	12,253	3,003	-26.6%	9,865	2,418	-40.9%
Shikama	7,238	6,405	5,707	5,050	-21.2%	4,875	4,314	-32.6%
Misato	24,852	6,229	18,610	4,664	-25.1%	15,168	3,802	-39.0%
Kami	23,743	7,109	16,605	4,972	-30.1%	13,163	3,941	-44.6%
Agglomeration	205,925	5,741	170,818	4,762	-17.0%	148,805	4,148	-27.7%
Tome	81,959	6,121	62,595	4,675	-23.6%	52,047	3,887	-36.5%
Kurihara	69,906	5,106	48,036	3,509	-31.3%	37,496	2,739	-46.4%
Agglomeration	151,865	5,608	110,631	4,085	-27.2%	89,543	3,307	-41.0%
Kesenuma	64,988	2,870	43,466	1,920	-33.1%	33,396	1,475	-48.6%
Shiroishi	35,272	4,101	25,888	3,010	-26.6%	20,676	2,404	-41.4%
Kakuda	30,180	4,723	23,282	3,644	-22.9%	19,074	2,985	-36.8%
Minamisanriku	12,370	3,156	8,349	2,130	-32.5%	6,451	1,646	-47.8%
Maruomori	13,972	5,611	8,566	3,440	-38.7%	6,231	2,502	-55.4%
Zaō	12,316	6,998	9,432	5,359	-23.4%	7,703	4,377	-37.5%
Shichikashuku	1,461	4,713	822	2,652	-43.7%	607	1,958	-58.5%

(source: own illustration, based on MIC, 2017a; MIC 2017b and eCitizen, 2018)

APPENDIX 14 B | AREA OCCUPATION – PROSPECTIVE REVELOPMENT

Assumes that all settlements have a population density in the build-up area of at least 8,000 Inh./km².

The change in km² refer to the estimated area of the base year 2015.

	2015 Area [km ²]	2035 Population [Inh.]	Area [km ²]	Δ [km ²]	Δ [%]	2045 Population [Inh.]	Area [km ²]	Δ [km ²]	Δ [%]
Miyagi (Prefecture)	473.59	2,046,219	255.78	-217.81	-46%	1,809,021	226.13	-247.46	-52%
Sendai	185.72	1,015,478	126.93	-58.79	-32%	922,655	115.33	-70.39	-38%
Natori	9.80	80,769	10.10	0.30	3%	76,595	9.57	-0.23	-2%
Tagajō	19.70	52,741	6.59	-13.11	-67%	45,821	5.73	-13.97	-71%
Shiogama	13.68	2,409	5.30	-8.38	-61%	35,625	4.45	-9.23	-67%
Iwanuma	7.94	41,369	5.17	-2.77	-35%	37,355	4.67	-3.27	-41%
Rifu	15.77	36,959	4.62	-11.15	-71%	35,037	4.38	-11.39	-72%
Watari	10.67	26,834	3.35	-7.32	-69%	22,154	2.77	-7.90	-74%
Taiwa	7.40	27,399	3.42	-3.98	-54%	24,968	3.12	-4.28	-58%
Yamamoto	2.68	8,854	1.11	-1.57	-59%	6,806	0.85	-1.83	-68%
Ōsato	4.25	6,224	0.78	-3.47	-82%	5,018	0.63	-3.62	-85%
Tomiya	12.64	58,051	7.26	-5.38	-43%	56,822	7.10	-5.54	-44%
Shibata	8.90	35,201	4.40	-4.50	-51%	31,280	3.91	-4.99	-56%
Ōgawara	6.09	22,079	2.76	-3.33	-55%	20,110	2.51	-3.58	-59%
Shichigahama	5.25	14,426	1.80	-3.45	-66%	11,906	1.49	-3.76	-72%
Matsushima	3.81	10,606	1.33	-2.48	-65%	8,496	1.06	-2.75	-72%
Murata	1.58	8,857	1.11	-0.47	-30%	7,293	0.91	-0.67	-42%
Kawasaki	1.59	6,497	0.81	-0.78	-49%	5,069	0.63	-0.96	-60%
Ōhira	1.32	4,855	0.61	-0.71	-54%	4,148	0.52	-0.80	-61%
Agglomeration	318.79	1,499,608	187.45	-506.24	-41%	1,357,158	169.64	-488.43	-47%
Ishinomaki	36.58	107,494	13.44	-23.14	-63%	6,697	10.84	-25.74	-70%
Higashimatsushima	6.45	33,841	4.23	-2.22	-34%	29,655	3.71	-2.74	-43%
Onagawa	2.71	4,022	0.50	-2.21	-81%	3,025	0.38	-2.33	-86%
Agglomeration	45.74	145,357	18.17	-63.91	-60%	119,377	14.92	-60.66	-67%
Ōsaki	23.33	117,643	14.71	-8.62	-37%	105,734	13.22	-10.11	-43%
Wakuya	4.08	12,253	1.53	-2.55	-62%	9,865	1.23	-2.85	-70%
Shikama	1.13	5,707	0.71	-0.42	-37%	4,875	0.61	-0.52	-46%
Misato	3.99	18,610	2.33	-1.66	-42%	15,168	1.90	-2.09	-52%
Kami	3.34	16,605	2.08	-1.26	-38%	13,163	1.65	-1.69	-51%
Agglomeration	35.87	170,818	21.35	-57.22	-40%	148,805	18.60	-54.47	-48%
Tome	13.39	62,595	7.82	-5.57	-42%	52,047	6.51	-6.88	-51%
Kurihara	13.69	48,036	6.00	-7.69	-56%	37,496	4.69	-9.00	-66%
Agglomeration	27.08	110,631	13.83	-40.91	-49%	89,543	11.19	-38.27	-59%
Kesenuma	22.64	43,466	5.43	-17.21	-76%	33,396	4.17	-18.47	-82%
Shiroishi	8.60	25,888	3.24	-5.36	-62%	20,676	2.58	-6.02	-70%
Kakuda	6.39	23,282	2.91	-3.48	-54%	19,074	2.38	-4.01	-63%
Minamisanriku	3.92	8,349	1.04	-2.88	-73%	6,451	0.81	-3.11	-79%
Maruomori	2.49	8,566	1.07	-1.42	-57%	6,231	0.78	-1.71	-69%
Zaō	1.76	9,432	1.18	-0.58	-33%	7,703	0.96	-0.80	-45%
Shichikashuku	0.31	822	0.10	-0.21	-67%	607	0.08	-0.23	-76%

(source: own illustration, based on MIC, 2017a; MIC 2017b and eCitizen, 2018)

