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Development of a generic Smart City model using MARVEL

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Abstract

The concept of the 'smart city' is seen as double edged sword that should alleviate societal and environmental problems as well as fuel economic growth. Literature has identified many important characteristics of Smart Cities but has not yet provided a systemic approach that describes the interdependencies between these characteristics. The current study was conducted in support of an integrated approach for developing smart city initiatives. We used group model building and interviews together with the MARVEL method to describe the interrelations between People, Environment, Living condition, Governance, Economy and Mobility. MARVEL is a method and a tool for developing CLD-like causal models. The model forms the basis for a systemic framework to supports diverse sets of stakeholders in the development and analysis of future smart city initiatives. We demonstrate how various functions of MARVEL can be used to perform qualitative analysis to this end.

Introduction

In the past decades the global population of urban areas has exceeded that of rural areas. By 2050 it is expected that global urban population will exceed that of the 2002 world population (UN-ESA, 2012). Urban population growth in the developed world is expected to experience relative little growth (1 billion in 2011 to 1.1 billion in 2050) with urbanization coming to a halt at a 0.5% to 0.3% yearly growth rate in urban population (UN-ESA, 2012; UNFPA, 2007). Nonetheless, 82% of Europe's population will live in urban areas by 2050 (UN-ESA, 2012). The population of the European Union (EU) is spread across many cities, at the moment 468 can be identified with a population exceeding 100 thousand (EU-PD, 2013).

In the industrial revolution Europe's cities have already put many of the dystopian effects of urbanization behind them, but, challenges remain. The economic, environmental and social dynamics of European cities lead to the following challenges being identified (EU-RP, 2011):

- Demographic change (Aging)
- Stagnating economic growth
- Income disparities
- Social polarization and segregation
- Spatial segregation
- Society dropouts
- Pressure on eco-systems.

Besides challenges from within, European cities are also faced with growing competition between one another. Market and law integration and growing dependence on service economies has led to increased homogeneity. As a result, cities are forced more and more to compete on similar characteristics as opposed to competition based on innate qualities related to geographic location.

Although facing challenges, cities are seen as the key for economic, social and environmental progress as was made explicit in the EU Horizon 2020 goals[1]. Cities are seen as places for connectivity, creativity and innovation and the engine of Europe's economy. The European city of tomorrow is envisioned to be a place of attraction, growth and a platform for democracy. A city that combines social progress with strong social cohesion, and that offers socially balanced housing and accessible social, health and educational services (EU-RP, 2011).

The '*smart city'* concept has become the central idea to which cities are now turning to face their challenges and pursue the demands put on them. This is illustrated by a European Commission study to assess how a wide variety of smart city initiatives contribute to the horizon 2020 goals and funds being made available for such initiatives (EU-PD 2013). However, many definitions of a smart city exist and the use of the word 'smart' is used in a self-congratulatory fashion (Hollands, 2008). Many existing studies of smart cities focus on certain types of interventions, often ICT driven, or on output metrics describing how well a city scores on criteria such as international access or level of education. (EU-PD, 2013; Giffinger et al. 2009). What these studies do not provide is a systemic description of how different characteristics of a smart city are interrelated. In the TNO research program 'Smart Cities' we chose to approach the smart city concept in a holistic manner.

In the remainder of this paper we will discuss the smart city concept and our modeling approach. The resulting model describes the complex feedback mechanisms that interconnect various variables identified as characteristics of a smart city. Furthermore, will demonstrate how using the functionalities of our approach can assist in analysis of the model structure and smart city interventions. In the discussion we will briefly discuss two applications of the model to date.

Smart Cities

In both applied and scientific publication the concept 'smart city' is used in a variety of ways: as an ability that cities possess, as a container to denote various initiatives and innovations, and as a label used by cities themselves. Especially this last use of the smart cities concept has received considerable criticism. Being 'smart' is by definition seen as a positive attribute. Who doesn't want to be smart? The latter makes it difficult to separate hype and marketing on one side and useful innovations and a critical perspective on the future of cities on the other (Hollands, 2008).

In a polemic article Hollands (2008) assesses the current use and promise of the smart city concept. He discusses a number of key elements found in frameworks as well as case studies. The following elements are identified:

- Networked infrastructure (especially ICT)
- Public-private partnerships, co-operations and communities of interest.

[1] 75% employment, 3% of GDP invested in R&D, 20-30% reduction in Co2 emissions, 20% of energy supply from renewables, 20% increase in energy efficiency, rate of school leave <10%, 40% of 30-34 year olds completed third level education, reduction in the number of people at risk of poverty or social exclusion by 20 million.

- Better interfaces between authorities, commerce and citizens.
- Social learning, inclusion and community development
- ‘Soft infrastructure’ such as knowledge networks.
- Development of talent and social capital
- Economic growth
- Environmental sustainability
- Social sustainability: inclusiveness.

From the list above it is evident that there is not a single clear focus for the smart city concept: goals and interventions are mixed, as well as ‘hard’ aspect such as ICT infrastructure and ‘soft’ concepts such as ‘inclusion’. Although, there does seem to exist a strong emphasis on technological enabled solutions.

The inherently positive connotation of anything ‘smart’ combined with a lack of systemic appreciation of the impact of smart city initiatives leads to a danger of overlooking apparent contradictions in their (desired) outcomes, Hollands warns (2008). The emphasize on economic growth as the goal of many initiatives might lead to social segregation in cities if the ‘haves’ profit disproportionally from financial, knowledge and infrastructural improvements. Some initiatives seem to focus on meeting corporate needs vs. being socially smart. Furthermore, investing in technological development and infrastructure is not a guarantee for its adoption. Tension can also arise between potentially conflicting goals such as economic progress and environmental sustainability. When a tradeoff is faced between the two: what would be the appropriate choice for a smart city?

From the discussion by Hollands (2008) it is evident that if a city desires to be ‘smart’ it requires a broader vision than technological investments or economic goals. Based on a more recent set of literature Allwinkle and Cruickshank (2011) support this observation and emphasize the importance of ‘soft’ (e.g. knowledge, social) capital combined with (ICT enabled) networks that boost local social capital. They emphasize the importance of the triple helix (e.g. research institutions, government and commerce) as the organizational form to support development and implementation of initiatives.

At this point in the discussion we have gained some insight in what types of smart city initiatives exist and to what end they might be used. We do however not have an idea of ‘smartness’. That is: how does one measure the ‘smart’ in a city. Giffinger et al. (2007) develop a framework and collect data to do just that. Based on literature they form a broad framework of six characteristics that measure the ability of a city to be smart (Figure 1) (for a methodological description see: Lazaroiu and Roscia, 2012).

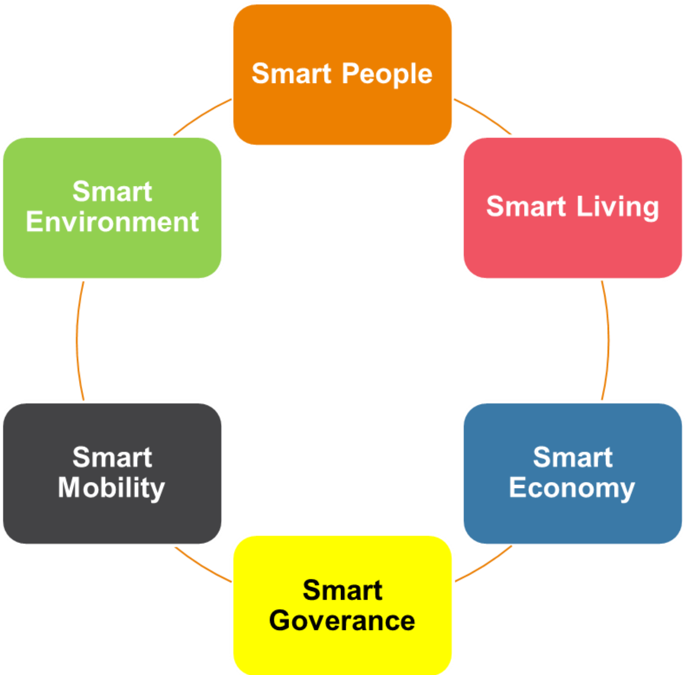


Figure 1 The six characteristics of smart cities (Giffinger et al., 2007)

The 6 characteristics are further divided into 31 factors which are subdivided into 74 indicators. Their measurements of 70 European cities provide a ranking of the cities but also individual score profiles[2]. The operationalization of the smart city concept by Giffinger et al. (2007) provides a way to specify goals, measure outcomes and provide input to discussion about the current standing of a city and potential interventions. The benchmark results offer a means for city officials to compare performance of their city to that of peers which might facilitate the transfer of successful policies. It might, however, also cause a city to focus on aspects it is already successful in. By its very nature the study structures characteristics, factors and indicators in a hierarchical fashion. It therefore does not directly provide insight into how the characteristics or factors might influence each other.

A study commissioned by the EU assessed the contribution of smart city initiatives to the Horizon 2020 goals (EU-PD, 2013). As a starting point they have selected the 6 characteristics laid out above. However, on a lower level the study identifies ‘components’ of initiatives. The components form means-to-ends and are seen as building blocks for initiatives, three categories are identified: technological, human and institutional. The study aims to be a vehicle for efficient allocation of funds and to identify examples of best-practice initiatives which are transferable and scalable. An inventory of existing smart initiatives is made and a selection of best-practices is developed. The study puts emphasize on different aspects of initiatives including a ‘holistic’ approach. The study provides insight into success factors for initiatives and the influence that initiatives can have on multiple characteristics. However, it does not provide a theory about how the characteristics or components are interrelated.

We can summarize this short discussion of relevant work as follows. The work by Hollands (2008) and Allwinkle and Cruickshank (2011) has given us an overview over a diverse field. The study by Giffinger et al. (2007) has structured it by providing a broad framework. Furthermore, they have

[2] For an interactive look at the data visit: www.smart-cities.eu.

operationalized the concept and provided measurements of performance. The EU study has provided an analysis of cases and has made the results actionable by providing drivers of performance at the initiative level (EU-PD, 2013). These studies, however, do not provide a systemic view on what a city is and how various aspects of the city, which are relevant for being 'smart', are interconnected. In the next section we will discuss why such a systemic view is needed as part of a project taking place within our own institution.

Case – TNO's Smart City Program

The current research was performed as a project within the research organization TNO. TNO is the largest research institute of the Netherlands employing 3800 people dedicated to implementing scientific knowledge in society. TNO efforts focus on 6 themes: Health, Industrial innovation, Integral security, Energy, Mobility, Build environment and Information society, all of which involve many different areas of expertise. At TNO it is recognized that innovation in one area can often benefit other areas and that collaboration across themes is necessary to face the challenges in society. TNO started a Smart Cities research program in 2013 in order to foster co-operation and develop an integrative approach to support decision makers to create 'cities of the future'. The program aims to develop an overarching approach that allows collaborative development of integrated smart city solutions that have a measurable impact on sustainable economic development and high livability standards while causing minimal pressure on natural resources and the environment. Within the program, smart cities are envisioned as a dynamic ecosystem of policymakers, businesses, citizens and knowledge institutions that co-operate to develop services and products that enhance innovation and that result in an attractive, competitive and sustainable city.

The current study was conducted in support of an integrated approach for developing Smart City initiatives. The study aimed to develop a systemic framework for TNO to support the development and analysis of future smart city initiatives. The process aimed to bring knowledge from a wide variety of expertise areas together to make the interrelations between these areas of expertise explicit. The study aims to accomplish these goals by building a model which makes the linkage between different characteristics of Smart Cities explicit. The process of building the model thus aimed to connect people within the institute while the final model aims to be re-usable in settings were the institute and many more stakeholders (city officials, citizens etc.) need to collaborate to develop smart city initiatives.

Method

This study was characterized by a very wide scope. The topic is abstract in the sense that it was not related to a specific case (e.g. a specific city or a specific formulation of the problem). It attempts to develop a generic and re-usable model of the interrelations between different characteristics that together make a city 'smart'. This also means that there is not a single variable of interest which displayed problematic behavior. A diverse set of topics falls under the smart cities umbrella and is addressed. This required the participation of experts from many different domains. In this section we will describe the type of model built and the process used.

Method to analyze relations using enriched loops (MARVEL)

The smart city concept does not only relate to tangible aspects and processes of a city but also to intangible ones, such as ‘social cohesion’. Although stock and flow models can include intangible variables they are difficult to represent in a manner that adds value beyond what is possible with simple word and arrow diagrams such as a causal loop diagram. Furthermore, since a participative model building process was needed we favored the use of a diagram type which would be easier to explain to laymen. However, the normal diagram of choice for system dynamics in such a case: the causal loop diagram, does not allow us to gain a quantitative insight into strengths and delays of relations. For these reasons we have selected MARVEL as the method of choice.

MARVEL is a method and a tool that builds on the foundations of system dynamics. It does so by slightly modifying the causal loop diagram while maintaining principle concepts such as delays. As a basis it adopts the causal loop diagram but also includes elements of other methods. For instance, MARVEL is similar to fuzzy cognitive maps in that it expresses influence in a simplified manner using strengths (Kosko, 1986). MARVEL also adopts the effective use of path analysis as is common in Strategic options development and analysis (Eden & Ackerman, 1998). The fundamentals of the method were first proposed by Erik van Zijderveld (2007) in an conference paper at the system dynamics conference. In the past 7 years MARVEL has been growing in popularity as a problem structuring method within TNO and its partners. Based on experiences and research MARVEL has also been refined. Most notably is the development of new software which facilitates model analysis through (quantitative) path analysis, loop analysis and simulation. A MARVEL diagram is composed of variables and relations. The variables denote the state of the system. Variables are named following standard system dynamics conventions as for instance described by Sterman (2000, p. 152). Relationships express a causal effect of one variable on the other. They have a polarity, strength and delay. The strength of a relationship expresses to what extend a change in one variable will eventually lead to a change in the variable being influenced. However, unlike is common in Stock and Flow models materials do not flow from variable to variable in MARVEL. Instead, effects are propagated through a model. The delay expresses the amount of lag in the materialization of the effect.

The MARVEL tool offers some additional features which facilitate the discussion about structure and behavior. By automatically highlighting variables based on a criteria of interest the user can conveniently explore even very complex models. The main uses of these functionalities are:

- Highlighting all variables affected by a variable of interest and subsequent first, second and third order relations.
- Highlighting all variables that influence a variable of interest and subsequent first, second and third order relations.
- Highlight all paths between two variables of interest.
- Highlight feedback loops in the model.

When strengths and delays have been indicated the latter two functionalities will deliver their output ranked according to the power of the path or loop (e.g. more powerful loops or paths are displayed first). Since, an effect is propagated from variable to variable via relations we take the product of the strength of the relations. However, the speed at which an effect materializes also influences the dynamics of the system and can thus not be ignored. Power for both paths and loops is calculated with the following equation (where *i* is a relation):

Equation 1 Calculation of power for loops and paths

$$\prod_{i=1}^{n}(\boldsymbol{Strength_i}) \,/\, \sum_{i=1}^{n}\left(\frac{\mathbf{1}}{\boldsymbol{Speed_i}}\right)$$

We will demonstrate the application of these functionalities in the result section. Since simulation was not used in the current study further elaboration on the operations of MARVEL is beyond the scope of this paper.

Process

The project was conducted by a team of three of which one acted as a facilitator during sessions, all three shared responsibilities for interviews and model building. We can divide the project in roughly three phases, of which the last stage is still ongoing. The first phase concerned the problem definition and initial model building done in a Group Model Building (GMB) fashion. The second phase concerned model refinement mainly based on interviews. The third phase concerns the further implementation of the model so as to develop it as a tool which can be used in analysis and decision making processes.

The main aim of the first phase was to conceptualize the problem and to explore it together with a group of experts. It aimed to elicit knowledge and create a shared vision on important aspects of smart cities and their interrelations (including polarity). A powerful process for achieving these aims is group model building (GMB) (Vennix, 1996). GMB is a participative form of model building in which a group of stakeholders collaboratively build a model with the help of a neutral modelling team. A facilitator elicits the mental models of participants step-by-step during a discussion of relevant variables, causes and effects. Variables and relations are included in the model if the group reaches consensus about their usefulness and formulation. The model is gradually built up and projected 'live'. The structured elicitation, live projection of the model and help of a neutral facilitator create an atmosphere in which substantive discussion and synthesis occurs. The results is team learning which is captured in a model that expresses a shared view on the system (Vennix, 1996).

In total 5 GMB sessions of 4 hours were held. The group consisted of 7 TNO experts and included both generalists from the public policy domain as well as specialists from a variety of domains. Together the group's expertise covered the 6 characteristics laid out by Giffinger et al. (2007): People, Living, Environment, Governance, Economy and Mobility. In the first session the central question for the subsequent sessions was agreed on with the group: How can a city provide a good place to live, have high degree of economic vitality and be sustainable? Four central variables were selected from which the model building was started: Social living condition, Physical living conditions, Ecological footprint and Economic vitality.

In the subsequent sessions the group worked on developing the model in an iterative fashion. In-between sessions the modelling team re-organized the model to reduce clutter. At the start of each session the group was given a short review of the work done up to that point. This included highlighting loops and drawing attention to pieces of the model which were not part of the feedback structure or which seemed to be missing relations to other parts of the model. In session three the 6 characteristics of Giffinger et al. (2007) were introduced and included in the model as output variables (without being part of the feedback structure since the variables that make up the characteristics were already included in the model). All variables were categorized in six clusters following the six characteristics discussed. In between sessions participants were given small assignments that would serve as input in the discussion during the sessions. These assignments included: listing of ‘smart city’ interventions, identification of trends affecting Dutch cities and identification of ‘core’ qualities of cities.

To further refine the model in the second phase of the project an additional 13 interviews were held with a divers set of experts; some of which participated in the GMB sessions and some who did not. The purpose of these interviews was to validate the work done during the sessions. At least one interview was held related to each of the 6 clusters in the model. During the interviews the modelling team presented the model and navigated through the model with the expert in an interactive fashion. If additions or alterations were necessary these were made live together with the expert. The focus of the interviews was on an validation of specific clusters (coherence *within* a cluster) as well as clarifying the relations of the regarding cluster with variables outside of that cluster (coherence *between* clusters).

The resulting model was presented to the participants of the GMB process in a final session. During this session the discussion was focused on how the model might be re-used in the future. The participants gave input as to how their work and their clients might benefit from use of the model and which steps would be necessary to make this happen. Based on the information gathered during the whole process the modelling team, together with a generalist, quantified the relations (e.g. adding strengths and delays) in the model in 3 sessions of 4 hours each.

Results

Figure 2 displays a simplified version of the final model. The thickness of the arrow expresses the strength of the influence, the number of dashes at its tip the delay. More detailed discussion on the quantitative values in the model falls outside of the scope of the current paper. By any standard it is not a small model or one that explains certain dynamics. Rather, it is an exploration of which variables and relations are recognized as important for smart cities by the experts involved in the process. The model is of a size and complexity which makes unassisted analysis difficult. Therefore, in this section we will show how we can explore the model by using some of the functionalities MARVEL offers. The analyses demonstrated here are similar to those we use when applying the model in an analytical or policy formulation setting, which we will discuss in the discussion section. We will first briefly show the outcomes of one of our goals: describing how smart city characteristics influence one another. We will do this for each of the six characteristics by showing how the variables within the cluster of variables are related and by showing which variables outside of the cluster influence variables within the cluster.

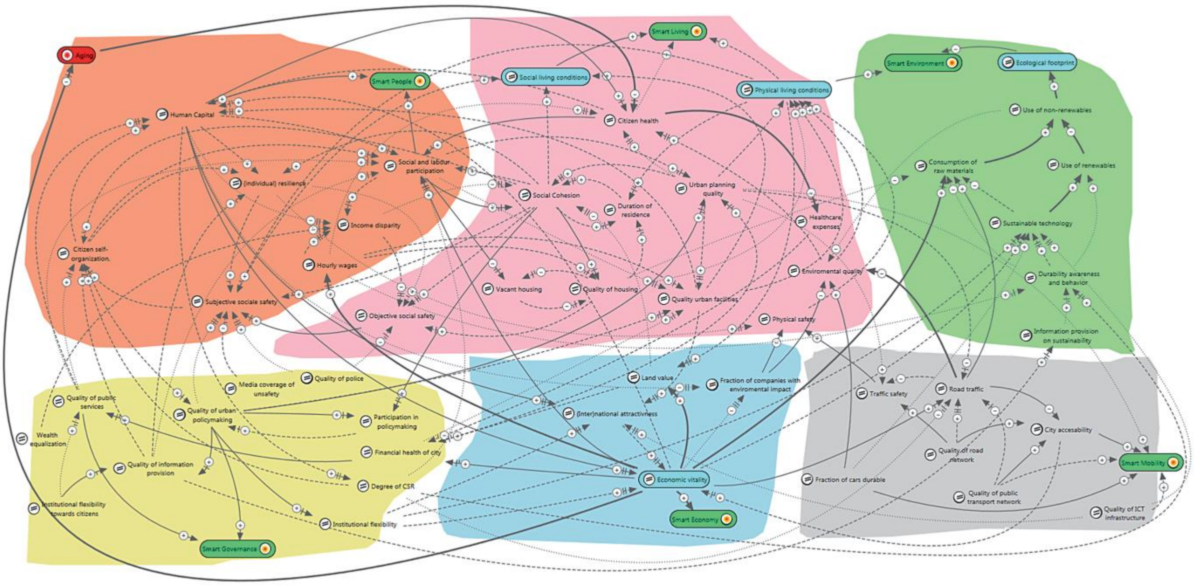


Figure 2 The TNO Smart City MARVEL model

Smart People

The prime aspects of the characteristic smart people is the 'soft' capital of the city. In the model this is expressed as human capital and the degree to which the people of the city participate in the labour and social processes. Other important aspects relate to income differences in the city and resilience of people. The Smart People cluster is influenced by Living, Governance and Economy. Most notably, citizen health and economic vitality.

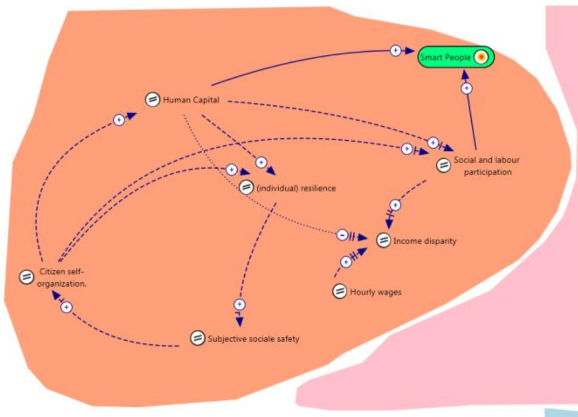


Figure 3 Variables and relations within the People cluster

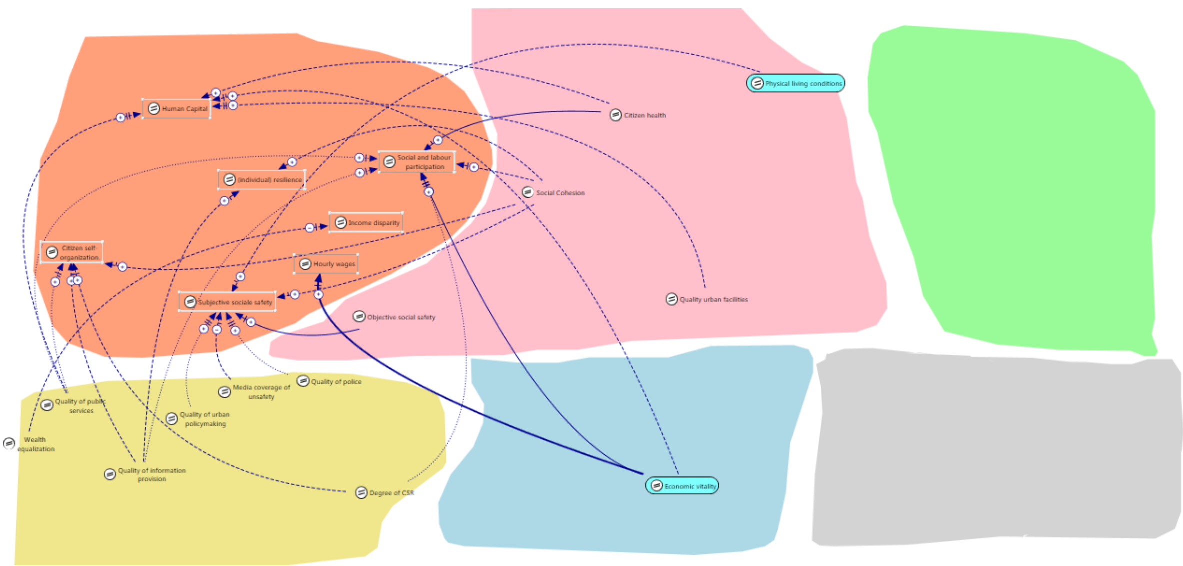
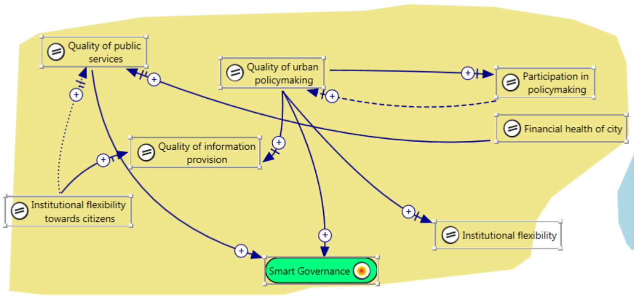


Figure 4 Variables that influence the People cluster

Smart Governance

Smart Governance describes the the quality of urban policymaking and the functioning of public administration and services. In a smart city, policymaking will be transparant and will actively involve the citizens.



cluster

Smart Governance is influenced by People, Living and Economy. A strong influencer is economic vitality which influences the financial health of the city. A soft factor of importance is social cohesion. It is assumed that when social cohesion is stronger people will become more involved with city policy. Furthermore, from a people perspective, self-organization of citizens also improves governance.

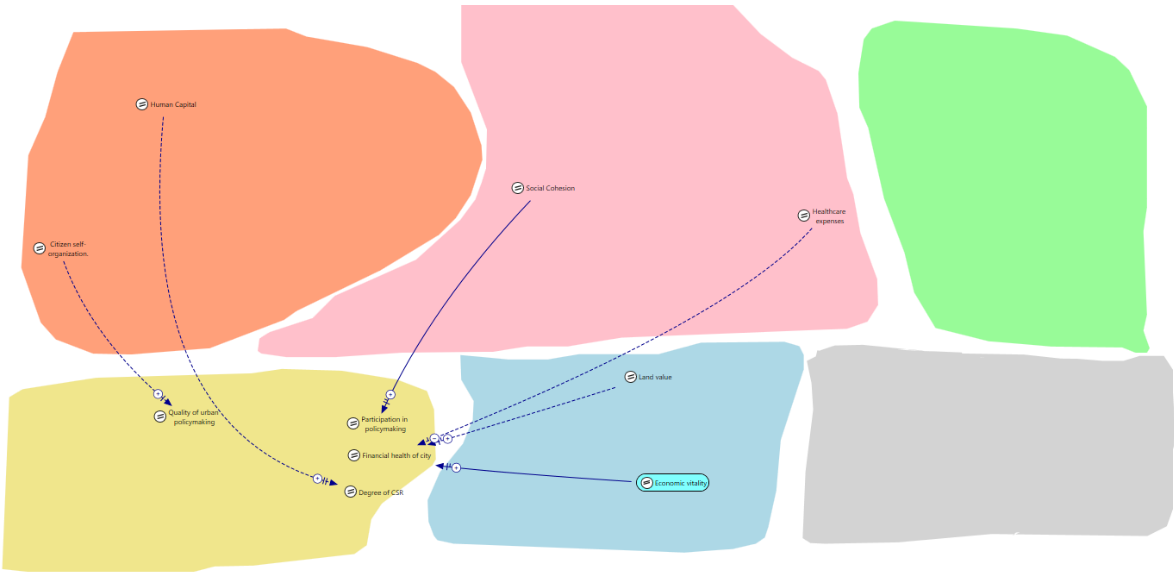


Figure 6 Variables that influence the Governance cluster

Smart Economy

The characteristic Smart Economy has for the largest part been captured in one variable: economic vitality. Economic vitality expresses the economic productivity of the city. (Inter)National attractivness strengthens the economic vitality of the city.

The strongest influence on economic vitality is exerted by the abilities of the people in the city: the human capital, which both influences economic vitality directly as well as indirectly through attractivness. Other influences on the cluster economy are originating from: Living, Governance and Mobility.

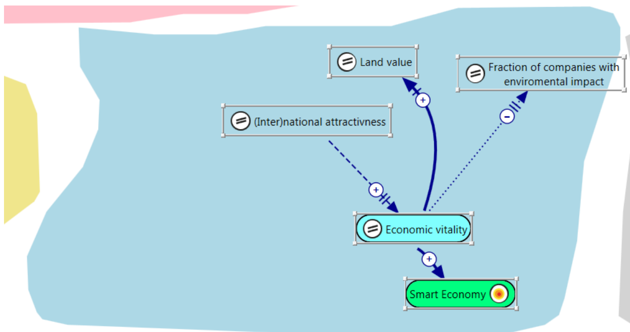


Figure 7 Variables and relations within the economy cluster

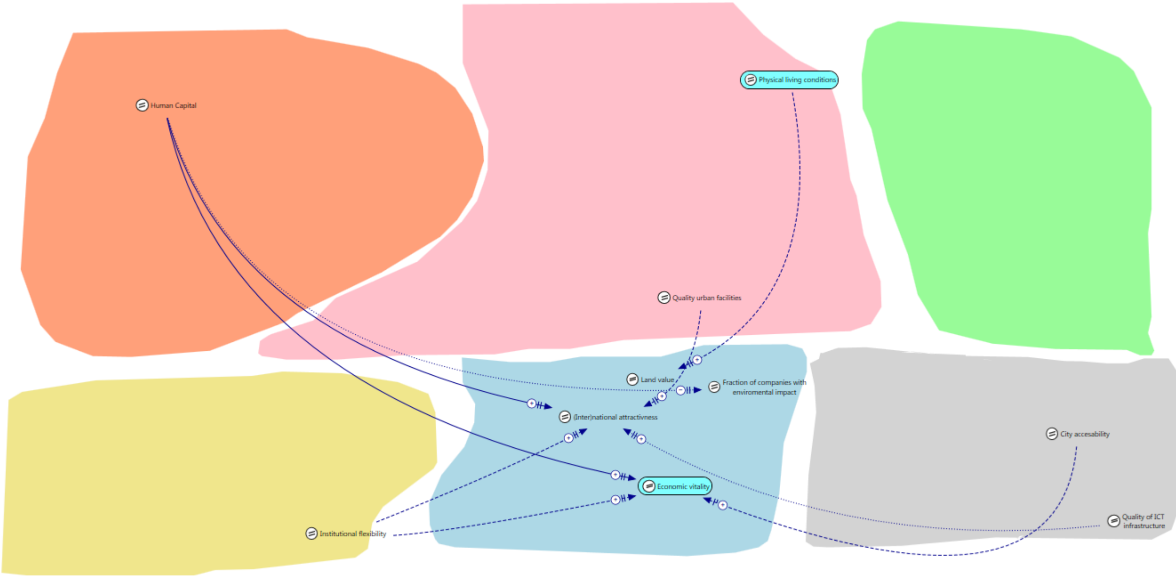


Figure 8 Variables that influence the Economy cluster

Smart Living

Smart Living expresses the quality of life in the city. It has two tightly coupled dimensions. Firstly, social living conditions, of which social cohesion is an important aspect. Secondly, physical living conditions, of which aspects such as environmental quality and urban planning as important factors.

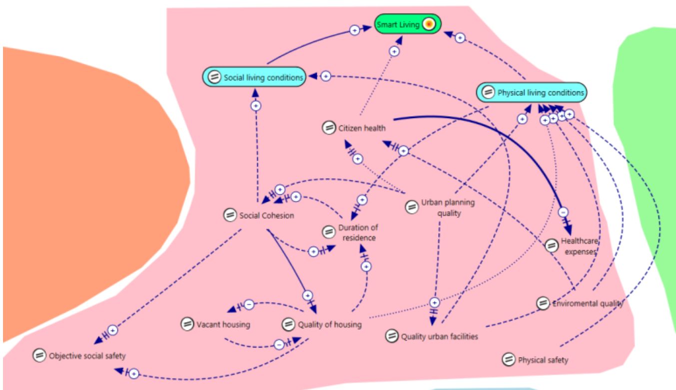


Figure 9 Variables and relations within the Living cluster

The Living cluster of the city is coupled with all five other clusters. Social aspects are strongly influenced by people aspects such as human capital and social and labor participation. Physical aspects are influenced by the quality of urban policymaking and financial issues from both the governance and economic cluster. Mobility and the use of non-renewables has an impact on the environmental quality of the city.

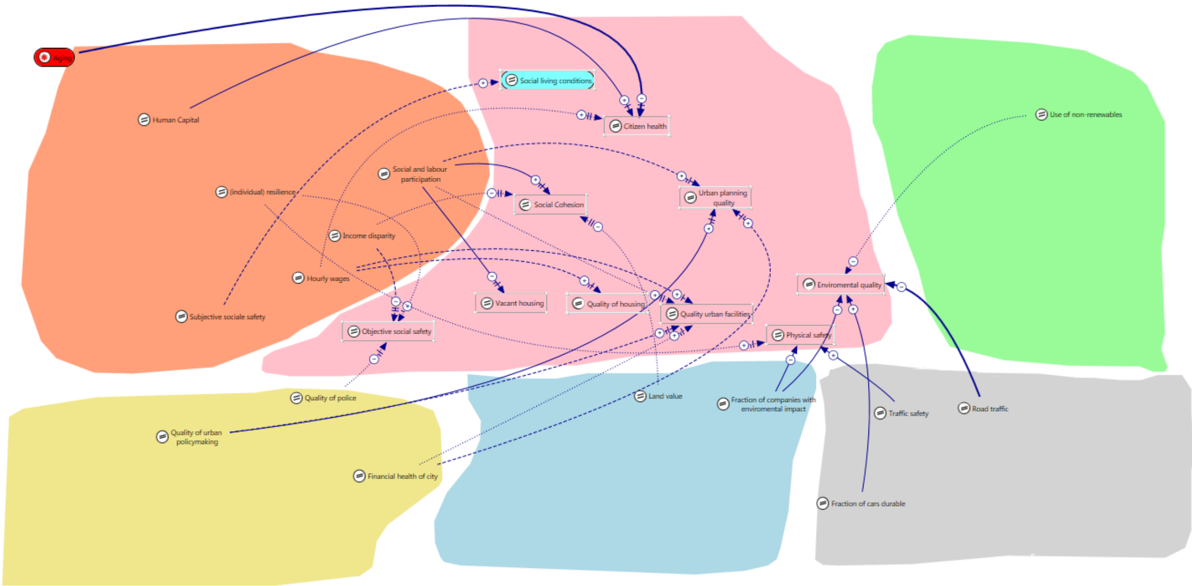


Figure 10 Variables that influence the Living cluster

Smart Environment

Smart Environment mainly describes the ecological footprint of the city. It is influenced by the use of renewables and non-renawables. In turn these are influenced by three key aspects, the consumption of materials, the level of sustainable technology implemented and the awareness and behavior related to durable consumption.

All clusters affect the environment but in different ways. Economy and mobility have strong effects on the consumption of materials. While governance mainly influences sustainable technology and durability awareness and behavior.

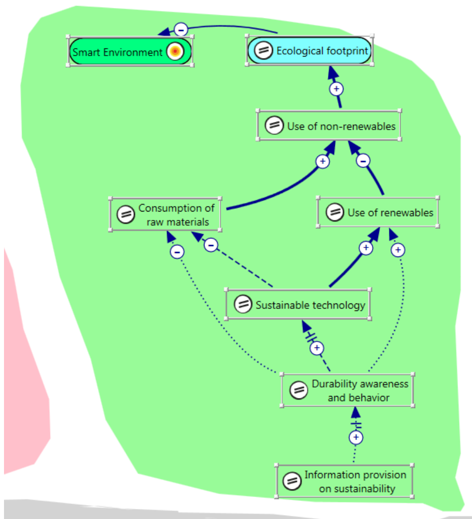


Figure 11 Variables and relations within the Environment cluster

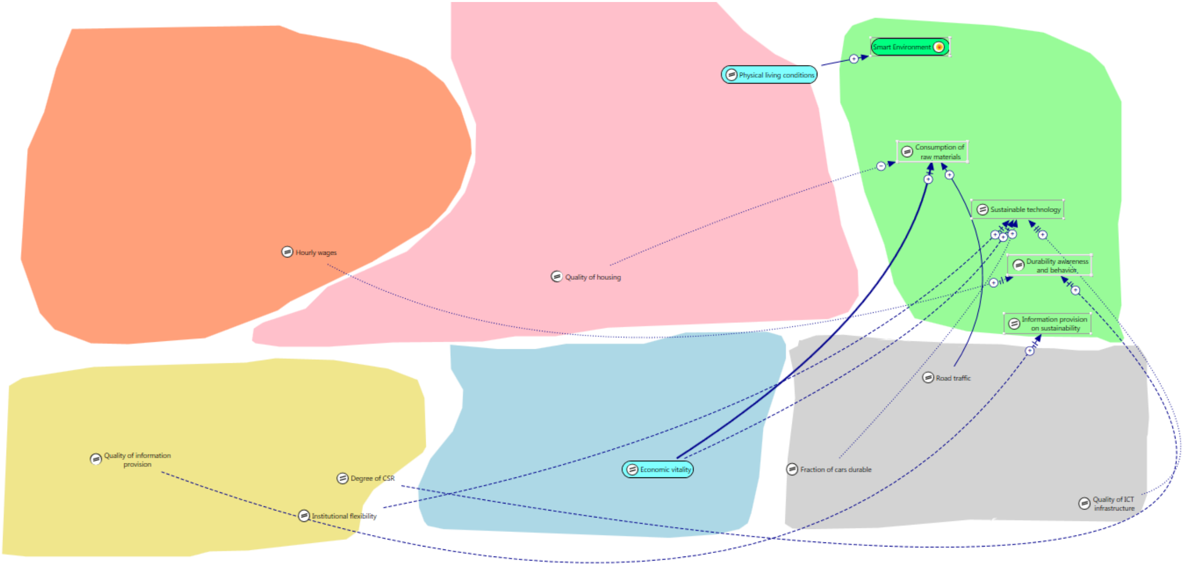


Figure 12 Variables that influence the Environment cluster

Smart Mobility

Smart Mobility describes the city accessibility both by different modes of transport and ICT.

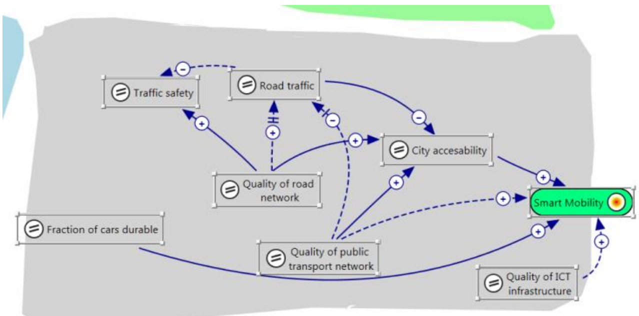


Figure 13 Variables and relations within the Mobility cluster

An important aspect that determines the amount of traffic in the city is the economic vitality. Urban planning quality can reduce the amount of traffic by reducing urban sprawl and making cities accessible by bike or foot.

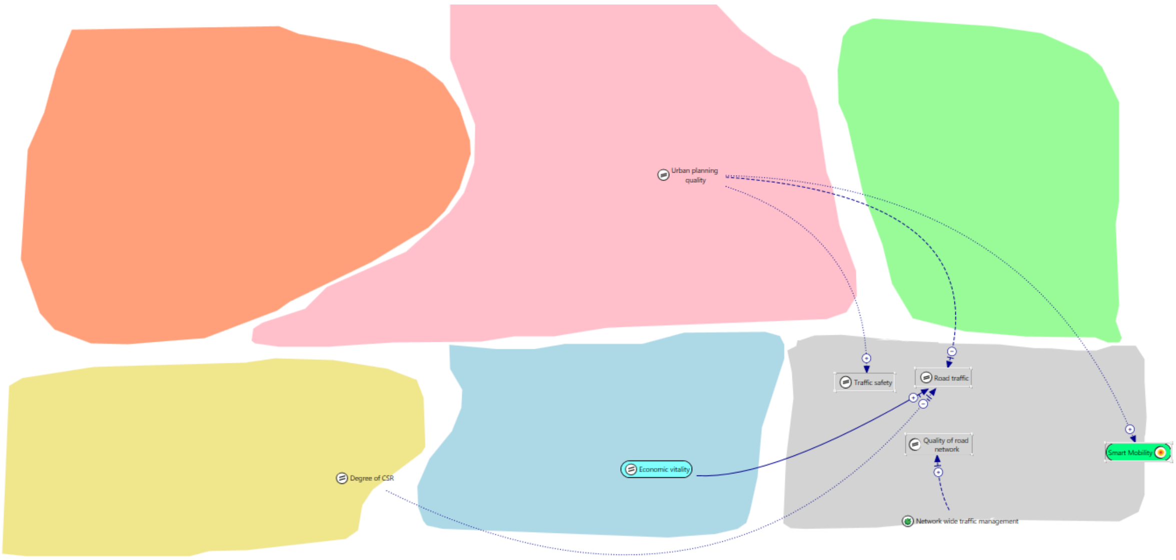


Figure 14 Variables that influence the Mobility cluster

Analytical tools

Loop Analysis

The model has a broad scope and focusses on the interrelations between the clusters formed on the basis of the six smart city characteristics. A result of this is that many local feedback mechanisms (local referring to a characteristic cluster) are not included in the model but are enclosed in high level variables. The clusters: economy, environment and mobility have no local feedback loops at all. However, if we take a bird eye view off the model, we find an enormous amount of feedback mechanisms. These result from the effort put into describing how one characteristic might influence another. Since, the model is not build to explain problematic behavior it is not possible to discuss key-feedback loops driving behavior. However, feedback loops can still be identified and can serve as input for discussing interventions and policies. Figure 15 provides an example. It shows how a feedback loop spans across 3 different clusters of the city. It reminds us of the ‘success to the successful’ archetype. The higher the economic vitality of the city, the better it’s financial health, the better the public services (e.g. education, welfare) it can provide for its inhabitants which will result in higher social capital which in turn leads to a higher economic vitality. Using equation 1 we can also determine the relative power of this particular loop. We find it is the 13th strongest loop in the model. Ranking loops and paths can help to focus the attention of users on the most influential parts of the model. The loop analysis tool is from a system dynamics perspective the most important form of analysis. It helps the user discover which variables interact to generate endogenous behavior. This brief example shows how feedback loops can span multiple characteristics.

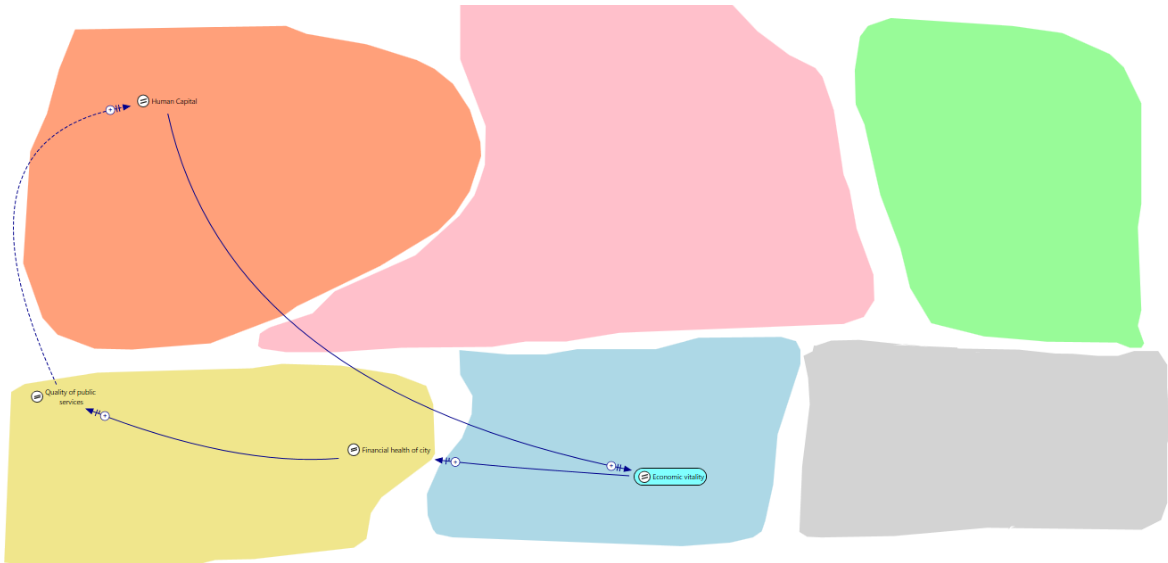


Figure 15 Example of a feedback loop spanning multiple clusters

Highlighting effects and Path analysis

We can use the model in combination with MARVEL functionalities to analyze smart city initiatives (so-called interventions). For instance, one of the client’s projects focusses on ‘network wide traffic management’. This innovation aims to optimize the use of existing road networks to increase capacity and safety. A high level model like the smart city model does not capture all the details of how such an innovation might be implemented. However, the policy logic behind such a project can be inspected on a high level by using MARVEL functionalities. To do this we introduce an intervention variable in the model: ‘network wide traffic management’. By using what we refer to as the highlight function, we can map all first, second and third order effects of this intervention (see Figure 16). This provides the user with a quick insight into how the intervention influences the variables in the model.

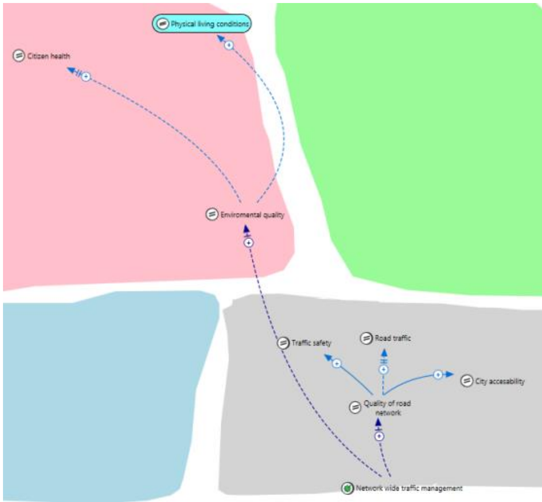


Figure 16 Example of highlighting the first and second order variables affected by an intervention

We can also look at how the intervention might affect a specific variable. For instance, we might be interested in how the intervention influences the Smart Living characteristic. For this we can use a path algorithm to determine all paths between the intervention variable and a goal variable (in this case Smart Living). In a model with this degree of complexity this will lead to an overwhelming number of paths. However, based on Equation 1 we can rank these paths according to power. Figure 17 shows the strongest path with a positive polarity (dark blue path). The intervention is assumed to improve the environmental quality because it reduces traffic emissions which leads to better physical living condition. However, we can also identify two rather similar paths with a negative polarity (light blue paths). Both of these paths increase road traffic, since higher quality road network is assumed to attract more cars. Furthermore, it is expected to increase accessibility, which increases the economic vitality of the city, which generates even more road traffic. The increase in road traffic has a negative effect on environmental quality which reduces the physical living conditions. The latter two paths might thus offset the initial benefits gained by the intervention. Such analysis can aid the discussion on effects and side-effects of interventions.

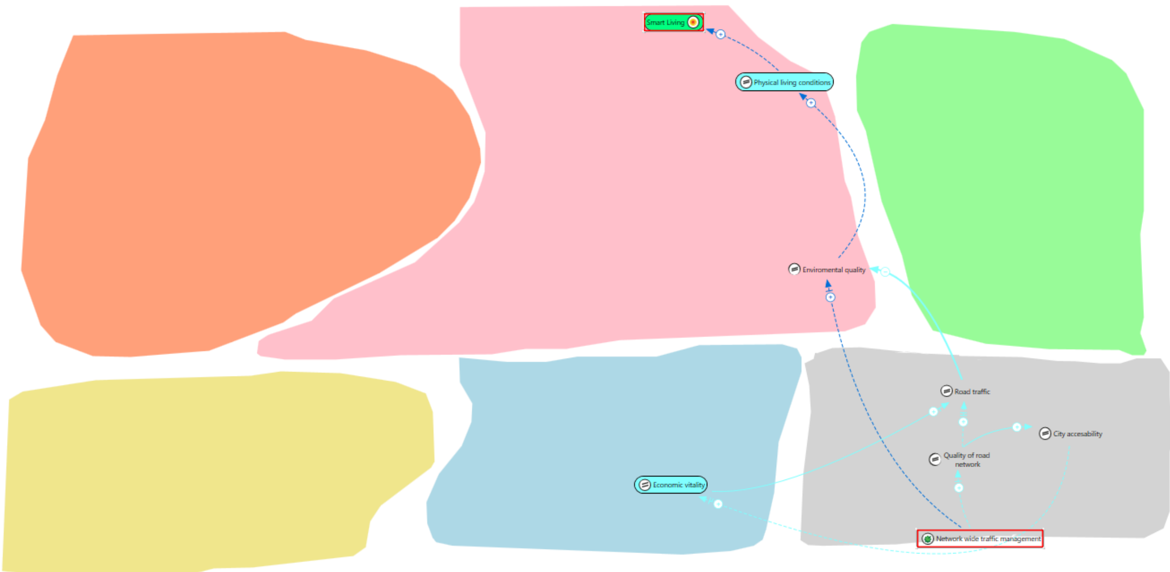


Figure 17 Example of how path analysis can be used to identify relevant paths between an intervention (network wide traffic management) and a goal variable (Smart Living)

Discussion

A MARVEL model was built that describes the variables and relations which are relevant for a city to be a good place to live, have a high degree of economic vitality and be sustainable (a smart city). This model was developed along the six characteristics laid out by Giffinger et al. (2007): People, Living, Environment, Governance, Economy and Mobility. It is a representation of how the experts included in the process view feedback structure underlying these characteristics. To validate the results of the group model building process additional interviews were conducted. The model offers a systemic view on the smart city concept and can aid in evaluating how challenges and initiatives impact a city. To our knowledge existing literature has focused on either measuring output or determining best practices for smart initiatives (Giffinger et al., 2007; EU-PD, 2013). There is only a limited systemic or causal theory underlying these studies. In this regard, the current study takes on a new perspective on smart cities.

The primary goal of our work was to develop a re-usable model that could serve as a tool for analyzing and developing new smart city initiatives by determining how these initiatives influence smart city goals. We have demonstrated how path and loop analysis can be used to this end. Together with city officials, we are now discussing how the model can be used in their practice. So far we have applied the model on one occasion and a second larger project is scheduled.

The model was used to assist representatives from a variety of research institutions and companies to formulate a joint research agenda. The model was used in an initial brainstorm-like session in which groups of representatives discussed potential avenues for future research on topics related to smart cities. Each group received a poster sized print out of the model as well as assistance from a model builder operating the smart city model on a laptop. The model was used to support the participants in formulating a future research agenda by illustrating how different topics fit into the causal structure and how innovations might influence a city.

A second application of the model and the process is planned for later this year in a medium sized Dutch city. The city in questions has developed a number of strategic goals and a portfolio of on-going and future projects. The city, however, has limited insight into the combined effects of the projects. In three GMB-like sessions city officials will formulate policy variables based on the projects and will discuss how these influence the variables in the smart city model. If necessary, the model will be expanded to incorporate details of importance for the city in question. In this way the city officials are able to determine in which ways the projects influence the goal variables they aimed to influence, but, also, which goals are not yet sufficiently addressed by the project portfolio. It is expected that this exercise will lead to a more holistic appreciation of the project portfolio.

Besides re-using the generic model for specific city topics the model serves as an example of what can be achieved with the method and process. In specific cases it might be more insightful to construct a problem specific model. This can be done via the same process and with the same method as used in the current study.

The model building process aimed to bring knowledge from a wide variety of expertise areas together to make the interrelations between these areas of expertise explicit. With respect to this goal our work was successful. This is evidenced by the observation that the model has become a central point of reference within the larger research program. Both building the model together with the participants and exploring it together by discussing interventions (with the help of the functionalities discussed) contributed to this end.

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