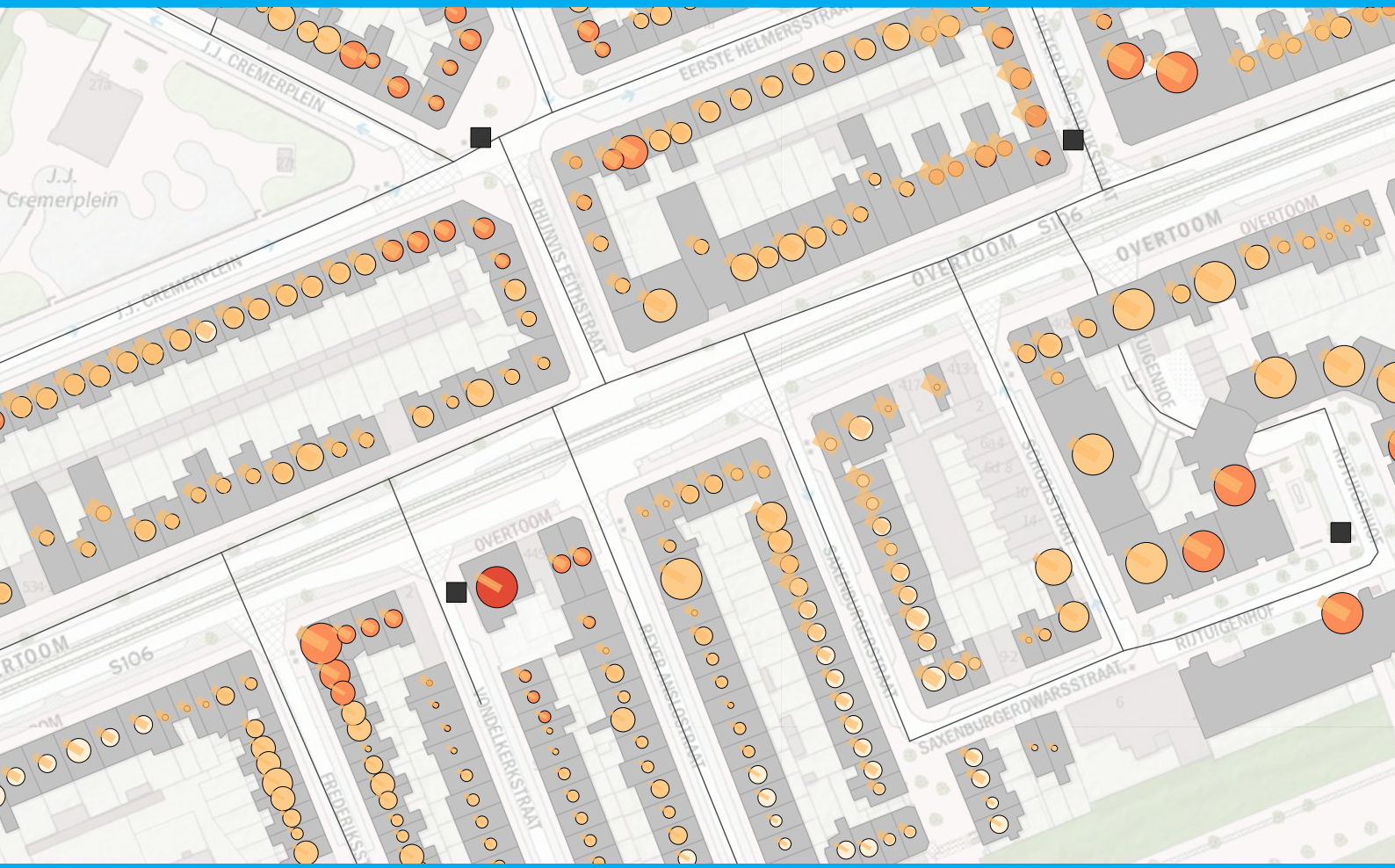
MSc thesis in Geomatics for the Built Environment

A Spatio-Temporal Method for Impact Assessment

Case study of the impact of organic waste collection system scenarios in Amsterdam

Roos Teeuwen

2018



TU Delft

A SPATIO-TEMPORAL METHOD FOR IMPACT ASSESSMENT: CASE STUDY OF THE IMPACT OF ORGANIC WASTE COLLECTION SYSTEM SCENARIOS IN AMSTERDAM

A thesis submitted to the Delft University of Technology in partial fulfillment of the requirements for the degree of

Master of Science in Geomatics for the Built Environment

by

Roos Teeuwen

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ABSTRACT

Amsterdam circular economy ambitions raise the question of what would be the impact of an organic waste collection system on inhabitants. Impact is an effect of a source on a receptor. Existing impact modelling studies describe impact either from source or from receptor perspective. In spatial planning, both source and receptor are variant over space. However, incorporation of the spatial dimension in existing impact modelling studies is limited, especially in presentation of outcomes.

The objective of this research is to answer: *what spatio-temporal method is suitable to assess the impacts of organic waste collection system scenarios in Amsterdam?* Tools used are QGIS and GRASS GIS, combined with PyQGIS scripting.

Five impact indicators were defined: three nuisance indicators (noise, odour and congestion), all quantified in three factors (intensity, temporality and affected population), and two sustainable planning indicators (CO_2 emission and waste collection), quantified in intensity factor only. Calculations are performed using simple theoretical principles, implemented from both source and receptor point of view.

It was found that basic spatial tools and calculation principles suffice to quantify impact spatio-temporally. For congestion and waste collection modelling network calculations are needed. All indicator outcomes except for CO_2 emission are relevant to present spatially. Both source and receptor point of view have their advantages and challenges, and therefore are complementing each other. Aggregation of factor values into one results in loss of information and transparency, which is contradicting to information and transparency gained by the high granularity spatio-temporal model. However, overview and simplicity in presentation of outcomes could be maintained by describing all impact factors per indicator in one clock-like marker. Impact assessment outcomes should be presented for individual sources and receptors. When presenting them on small scale, spatial aggregation into total values per neighbourhood is needed as well. Compared to presentation in a non-spatial graph, the spatial presentation of outcomes is of added value.

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ACRONYMS

BAG Basisregistratie Adressen en Gebouwen (Key Register Addresses and Buildings) . . . 19

GIS Geographical Information System . . . 2

MAUP Modifiable Areal Unit Problem . . . 4

OWA Ordered Weighted Averaging . . . 14

REPAiR Resource Management in Peri-Urban Areas. Going Beyond Urban Metabolism . . . 1

SAW Simple Additive Weighting . . . 13

VMA Verkeersmodel Amsterdam (Traffic Model Amsterdam) . . . 19

WDI Weighted Displaced Ideal . . . 14

WP Weighted Product . . . 14

1 INTRODUCTION

This thesis describes the graduation research on developing a spatial method for assessing the noise, odour, congestion, CO_2 emission and waste collection impacts caused by organic waste collection system scenarios in the city of Amsterdam. The research is the final part of the Master's Programme of Geomatics, at Delft University of Technology. It is building forth upon research and data provided by H2020 project Resource Management in Peri-Urban Areas. Going Beyond Urban Metabolism (REPAiR), led by prof. Arjan van Timmeren. In the following paragraphs the societal and scientific relevance of the project is highlighted. Afterwards, the research questions are elaborated on, the scope is set and relevant definitions are given. In addition, a reading guide to this thesis is given.

1.1 SOCIETAL RELEVANCE

CIRCULAR ECONOMY From a societal point of view, the challenge is found in the ambitions of the city of Amsterdam to become climate neutral [Circular Amsterdam et al., 2015]. Therefore, the municipality aims at establishing *Circular Economy*. Since this research project is building up upon the REPAiR research, the following REPAiR definition by Arlati et al. [2017] of Circular Economy is used:

> *Circular Economy is an economy based on renewability of all resources – energy, materials, water, topsoil (for food production) and air – while retaining or creating value, promoting positive systemic impacts on ecology, economy and society, and preventing negative impacts*

ORGANIC WASTE In 2015, the average Amsterdam inhabitant produced 92 kilograms of vegetable, fruit and garden waste [Municipality of Amsterdam, 2015]. In weight, organic waste forms the largest fraction in residual household waste: 25 percent in weight. It is expected that the number of inhabitants and therefore the amount of waste will increase further within the coming years.

Only 3% of all organic waste produced in Amsterdam is recycled or reused [Circle Economy, 2014]. Organic household waste in Amsterdam is only collected in a small area in the New Western part of the city: for all other parts of the city, organic waste ends up in a mix of residual waste [Municipality of Amsterdam, 2015].

From organic waste, production of protein for animal feed, bio gas and building blocks for chemical industry is possible, resulting in many economic and sustainability benefits [Circular Amsterdam et al., 2015]: by collecting this vegetable, fruit and garden waste, regenerative resource flows can be established according to Circular Economy principles.

COLLECTION SYSTEM SCENARIOS However, questions are raised on the feasibility of collecting organic waste separately in an urban environment and the impact such a collection system would have on its surroundings.

In addition, many alternative spatial scenarios can be implemented to achieve this, differing in, for example, the location of collection containers, routes along them and the schedule. Different scenarios can have different impacts on the city, its inhabitants and the environment. Often, these impacts vary spatially.

IMPACT As stated in the Circular Economy definition, negative impacts should be minimised. Examples of negative impacts are nuisance to inhabitants (i.e.noise and odour pollution, increased congestion) and the amount of CO_2 emission. On the other hand, the definition states that positive systematic impacts should be promoted. In this case positive impacts are described by the extent to which the collection system is usable for city inhabitants (i.e.the system is more easily usable for inhabitants when collection points are located close to their households) and thereby the total amount of organic waste collected separately from the general municipal solid waste.

1.2 SCIENTIFIC RELEVANCE

COMPLEXITY The impacts mentioned above differ from each other in character. This results in a complex decision making process. Therefore, there is a need to model different impacts separately and to integrate their assessment. Since both planning scenarios and their contexts are spatio-temporal, it is interesting to perform impact assessment using a spatio-temporal approach as well. According to Ferretti and Montibeller [2016], this allows an assessment which is tractable by decision-makers.

To achieve this, a method can be used that combines the spatial capabilities of Geographical Information System (GIS) and the capabilities of aggregation methods for decision making. In this field of research, both theoretical and practical research has been executed over the last two decades, but still it is very fragmented [Ferretti and Montibeller, 2016]. This research project therefore aims at tackling three technical challenges.

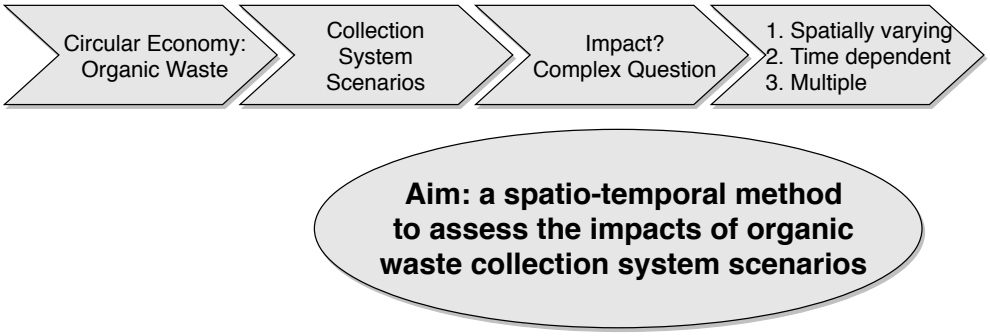
SPATIAL MODELLING Firstly, the challenge is to model the different impacts spatially. GIS software allows for spatial data storing, management, analysis and visualisation. However, no standard tools to spatially model impacts are available. Maps are of use for decision making since they abstract relevant information without involving unnecessary details [Mau et al., 2007].

TEMPORAL FACTORS Secondly, incorporation of temporal factors in these impact models is identified as a challenge. As elaborated on in the previous paragraph, GIS can be used for modelling geographical phenomena. However, temporal components are inherent to geographical phenomena as well [Peuquet, 2005]. Moreover, a central topic in GIS lies in representing change, since few domains are static [Mau et al., 2007]. For this research, examples of temporal factors are the moment of impact occurrence, duration of impact and the frequency with which the impact occurs. Antunes et al. [2001] identifies a subject of further development of their proposed spatial impact assessment method by extending it with evaluation of cumulative effects in time.

AGGREGATION Thirdly, the challenge lies in aggregating the different impact values, in order to maintain overview in the outcomes when communicating them with decision makers. Presentation of outcomes should allow transparent interpretation of outcomes by decision makers. Therefore, aggregation should be transparent as well. Important when choosing an aggregation method is define to what extent one value can compensate for another [Ferretti and Montibeller, 2016; Miller et al., 2013; Yager, 1988]. Many aggregation methods are available in literature.

The diagram in figure 1.1 shows the overview of the research societal and technical relevance described above. Chapter 2 elaborates on related research into the three technical challenges.

Figure 1.1: Relevance of the research



THE FIELD OF GEOMATICS As mentioned, this thesis is the final part of the Master's Programme of Geomatics at Delft University of Technology. The field of Geomatics covers spatial data collection, analysis, information modelling and visualisation with the aim of solving real world problems.

This research can be placed in between three topics addressed within the programme of Geomatics: GIS, Spatial Decision Support Systems and programming. Three corresponding courses within the Master's Programme of Geomatics can be identified.

Firstly, the course *GIS and Cartography* covers the concept of GIS, its components, its use in real world problems and using real world datasets and its spatial data visualisation abilities.

Secondly, the course *Python Programming* covers computational thinking and the ability of programming to solve a variety of computational tasks for spatial as well as non-spatial problems.

Thirdly, the course *Spatial Decision Support for Planning and Crisis Management* covers the use of spatial data to support the decision making process in spatial planning, characterised by complexity, and crisis management, characterised by urgency. The course focuses on the decision making process as well as the technical side of spatial decision support, thereby combining GIS and Python.

This research integrates computational thinking, spatial data analysis and spatial data visualisation in order to support decision making within a complex spatial planning topic.

1.3 RESEARCH QUESTIONS AND SCOPE

MAIN QUESTION AND GOALS The aim of this research is to answer the following main research question:

> *What spatio-temporal method is suitable to assess the impacts of organic waste collection system scenarios in Amsterdam?*

Three research goals can be linked to this research question.

1. The first goal is to assess the impact of a spatal planning scenario on its spatial context in a spatial manner.

2. The second goal is to incorporate temporal factors in this spatial assessment, resulting in a spatio-temporal assessment method. Examples of temporal factors are moment in time, duration and frequency of the impact, which might affect the impact significance.

3. The third goal is to aggregate the different spatio-temporal impacts in a coherent way, allowing for readable and transparent interpretation of assessment outcomes.

RESEARCH SUB QUESTIONS To arrive at an answer to the main research question, multiple sub questions have to be answered in advance. These are summed up below.

1. To what extent do existing impact assessment methods incorporate space?
2. How can the characteristics of each impact be modelled spatially?
3. How can temporal factors be incorporated in this spatial model?
4. How can aggregation principles be applied to integrate the different spatio-temporal impacts?
5. How do the outcomes of the spatio-temporal assessment method compare to the outcomes of similar non-spatial principles?

RESEARCH SCOPE This research has used the *MoSCoW* framework in order to set the scope clearly: tasks that *must* be done in order to complete the research, tasks that *should* be done because they are highly desirable, tasks that *could* be done and tasks that *will not* be done, but which might be relevant for the future.

The following paragraph describes what is within scope for this research, corresponding to *must* and *should* tasks. Subsequently, a paragraph described what is outside of the research scope, corresponding to the *could* and *will not* tasks.

TASKS WITHIN SCOPE – MUST AND SHOULD Research existing assessment methods; find and prepare data and scenario; define impact indicators; design the spatio-temporal assessment methods per impact indicator; research aggregation principles; design the overall spatio-temporal assessment method; implement the method using dummy spatio-temporal planning scenarios and real context data; compare the different alternatives of method components on their suitability for the purpose of the method; validate spatio-temporal method with non-spatial method.

TASKS OUT OF SCOPE – COULD AND WILL NOT Implement the method using real spatio-temporal planning scenarios; test the method with possible users; use case expert knowledge for assigning weights to criteria or for impact significance research; address the degree of uncertainty in the method; address the Modifiable Areal Unit Problem (MAUP) in the method; design a user interface to the method; validate the impact magnitude and significance with measurements and surveys; measure the added value of the methodologies compared to a non-spatial method.

1.4 DEFINITIONS

IMPACT This research defines *impact* following Rooijen and Nesterova [2013]; Cambridge University Press [2017] as:

The effect of a measure on a particular target group or situation affected

For this project, the measures concerned are organic waste collection system scenarios. These are technically referred to as impact *sources*. The group affected is the inhabitants of the city of Amsterdam, technically referred to as impact *receptors*.

This research focuses on two kinds of impacts: local short term impacts, expressing the level of nuisance to people living in surrounding areas of the planning scenario (noise, odour and congestion), and global long term impacts, expressing the level of sustainability achieved by implementing the scenario (CO_2 emission and amount of organic waste separately collected). Chapter 4 further elaborates on the choices and definitions of each impact.

The research takes into account three temporal factors in modelling the impacts: duration, moment in time and frequency.

SPATIO-TEMPORAL METHOD The aim of this research is to develop a spatio-temporal method suitable for comparison of impacts of organic waste collection system scenarios in Amsterdam. Following the definition of impact in the previous paragraph, an impact is always defined by a source and a receptor.

Both source and receptor for the case are spatially varying within the extent of the city. An example of this is that the containers are only located at specified locations within the city. On the receptor side, the location and therefore density of houses varies over space, as well as their characteristics.

In addition, impact sources are varying over time. An example of this is that containers in the city will not be emptied simultaneously, but spread over time. Temporal variance of impact receptors can be found in the experience of people: noise at night time can be experienced as more offensive that noise during the day.

This research therefore defines a *Spatio-Temporal Assessment Method* as a method allowing for comparison of scenarios on a variance level coherent with the spatial and temporal variance level of source and receptor.

OBJECTIVES, INDICATORS AND FACTORS An *objective* can be defined as a variable with a direction of preference [Ferretti and Montibeller, 2016].

To an objective, multiple *indicators* can be defined. An objective can be quantified using an attribute, for example contaminating particle per ton of soil [Ferretti and Montibeller, 2016].

To indicators, this research will define *factors*. Quantification of factors can be achieved by measuring or modelling variables.

WASTE The following definition of waste by European Parliament and Council [2008] is used by the REPAiR research project:

> *Any substance or object that the holder discards or intends or is required to discard*

The research scopes down to fruit, vegetable and garden waste. This choice was made since the average quantity per Amsterdam inhabitant in 2015 of these waste types combined is known. It is assumed that all of this waste is produced in households. From now on, fruit, vegetable and garden waste is referred to as *organic waste*.

1.5 READING GUIDE

This thesis starts with Chapter 2 on related researches into decision support, describing impact, spatial and temporal modelling and spatial application of aggregation principles.

Chapter 3 elaborates on the methodology which was followed to answer the research questions raised, as well as the data and tools needed to do so.

Chapter 4 starts with a conceptual overview of the impact assessment method developed. For each indicator and factor, it provides a detailed overview on how to quantify them, followed by an overview of spatial and factor aggregation principles which are to be tested.

Chapter 5 tells how the components of the method designed in Chapter 4 were implemented using the data and tools stated in Chapter 3. It starts with preparation and generation of data and scenarios, followed by tests and implementation of all the components of the method, together with their outcomes.

Chapter 6 provides an overview of all results coming forth from the implementation of the method. Results are divided into results concerning the quantification of impact factors, comparison of the two spatial point of views of impact, results on factor and spatial aggregation and visualisation of outcomes and finally, results concerning the comparison of non-spatial and spatial presentation of outcomes.

Chapter 7 conclusions are given to the research sub questions and the main question, followed by a discussion of the research and recommendations for future research.

In the appendices of the thesis, an elaborate methodological diagram, datasets, scenarios, a link to the implementation scripts and the outcomes of the final implementation are added.

2 THEORETICAL BACKGROUND

This chapter presents an overview of the relevant literature linked to the project. It is divided into five sections: research on decision support for waste handling planning; research on quantification of impact; research on spatial impact modelling; research on time in spatial modelling; and research on aggregation principles in spatial assessment. Based on the findings in this chapter, the focus of the research can be narrowed down further and a direction to how to solve the challenges mentioned in Chapter 1 can be identified.

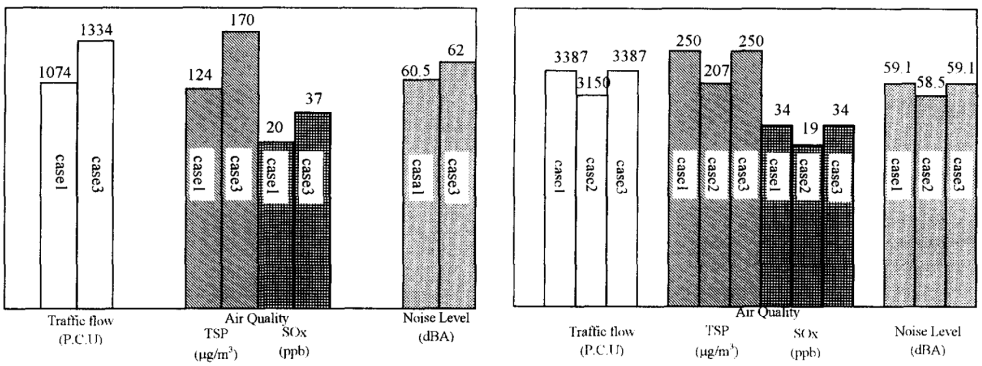
2.1 DECISION SUPPORT FOR PLANNING OF WASTE COLLECTION SYSTEMS

METROPOLITAN SOLID WASTE PLANNING Chang and Wang [1997] have developed a programming approach aiding at planning optimal Metropolitan Solid Waste systems, taking into account the fuzziness and complexity of system objectives. It quantifies different system scenarios in their costs and constraints. It focuses on the economic and environmental impact of noise, traffic congestion, air pollution and material recycling within the long term. Although the method takes into account spatial factors (location of system component, direction, distance) and temporal factors (moment in time) in its formulas to calculate costs (either economic or environmental), the impacts are not expressed spatially. Figure 2.1 shows their representation of outcomes, which is non-spatial according to the definition in Chapter 1.

WASTE PLANT DECISION SUPPORT Costi et al. [2004] developed an elaborate decision support method for solid waste plants, taking into account costs, constraints and impacts of a decision. However, it does not explicitly involve the spatial component.

MAPPING NEIGHBOURHOOD COMPOST UNITS IN AMSTERDAM Recently, some compost units (or in Dutch *wormenhotels*) have popped up in the city of Amsterdam. Inhabitants can bring their organic waste to the compost units, where worms convert waste to compost. Baas [2018] developed a method to calculate how many houses

Figure 2.1: Non-spatial presentation of impact (figure 6 in work by Chang and Wang [1997])



and how many people live within a certain proximity from a compost unit. From this information, a reachability score is calculated. Also, it calculates the mean duration from houses to the nearest compost unit. For calculation of distances, network analysis is used. The method uses open data from the municipality and uses Python to make calculations. Aim of the method is to determine where new compost units could be placed.

However, the method quantifies reachability rather than the impact of reachability. In addition, it does only address reachability and no other effects such as for example the odour emitted by the compost units.

2.2 DESCRIBING IMPACT

EVENTS AND IMPACTS Mau et al. [2007] define an event as a representation of a real-world occurent in a spatio-temporal data model. Spatio-temporal events are discrete in time and space, unique and countable. Peuquet [1994] describes spatio-temporal data, and therefore events, according to the Triad model. In this model, each entity has a spatial, temporal and thematic dimension: where, when and what happened?

Events can cause changes to the state of the model and these changes are then referred to as impacts [Mau et al., 2007]. Events and impacts are therefore related in both the spatial and the temporal dimension.

IMPACT AS ATTRIBUTE According to Mau et al. [2007], impacts in GIS can be described in quantitative or qualitative attributes. Quantitative attributes include nominal and ordinal attributes, such as types or ranks. Qualitative attributes include interval and ratio attributes, such as measurable values on a scale, either referencing to a fixed point or not.

MAGNITUDE AND SIGNIFICANCE Antunes et al. [2001] describe the difference between impact *magnitude* and *significance*. Magnitude represents the difference in environmental quality between the state with or without implementation of a spatial planning scenario. Significance represents the importance that is assigned by experts or public to that difference.

FIDOL PRINCIPLE FOR IMPACT OF ODOUR Freeman and Cudmore [2002] describe five factors influencing the impact of an odour, collectively known as *FIDOL*: *frequency*, *intensity*, *duration*, *offensiveness* and *location*. In their report, further explanation to these factors is provided, together with an extensive overview of theory, categories, usage and more. Nicell [2009] uses the FIDOL principle as a starting point for an odour impact assessment method. Although the factors include *Location*, both researches take geographical variation only to very limited and theoretical extent into account. Nicell [2009] does also take into account time to some extent by using average values per time interval.

2.3 SPATIAL IMPACT MODELLING

GIS CORE CONCEPTS Sileryte et al. [2017] propose a tool to assist local and regional authorities in integrated spatial development for Circular Economy purposes: Geodesign Decision/Discussion Support Environment. Such an environment requires impact modelling. To do this in a standardised way, they propose to model impacts using the five core content concepts of GIS. These are defined by Kuhn and Ballatore [2015] as: *Location*, *Field*, *Network*, *Object* and *Event*. *Locations* can describe static impacts on a specific location with irrelevant time stamps. *Fields*

can describe impacts following the first law of geography: *everything is related to everything else, but near things are more related than distant things* [Tobler, 1970]. Examples of these are cases where formulas describe any point or where interpolation or extrapolation can be used from known points. *Networks* describe phenomena which are related to each other in a way which is not necessarily spatial, such as health issues or material flows. *Objects* are able to represent either geographically located or non-geographically located objects, such as species or resources. Impacts on objects can be via network or via geographical relations, either temporal or non-temporal. *Events* can model any of the previous categories when it has a specific time of validity (i.e.start and end time).

SPACE IN MODELLING Kelly et al. [2013] identify four different ways to treat space in modelling. These are enumerated below:

1. *Lumped* spatial models: a model providing a single set of outputs for a spatial entity, for instance a model of a lake which does not consider the different parts of the lake explicitly.

2. *Region-based, compartmental* spatial models: a model providing a different set of outputs for each homogeneous sub-area of the total area modelled. Each area is homogeneous in one or more key characteristics, for instance a lake modelled in its shoreline vs. deeper parts, which are interacting in the model.

3. *Grid, cell or element-based* spatial models: a model providing sets of outputs on a uniform or non-uniform grid- or vector-based representation. Although neighbouring features might share key-characteristics, they are still modelled separately.

4. *Continuous* spatial models: outputs described by partial differential equations for instance. This type can be used for theoretical results, but in practice often discretised in one of the above spatial models.

With current technologies, high resolution data and high processing power of data analysis is feasible in GIS, allowing for spatial disaggregation of indicators. On the contrary, some level of aggregation is often needed for data collection and reporting purposes [Miller et al., 2013] and desired to allow for convenient interpretation and presentation. Miller et al. [2013] identify two types of indicator aggregation which mask heterogeneity in results and therefore constrain the level of nuance in a model: *spatial aggregation* and *temporal aggregation*.

When aggregating at spatial level, a degree of arbitrariness is often found: for instance when using census units or postal codes. the MAUP describes that if units are defined arbitrarily, analysis results are arbitrarily as well [Miller et al., 2013]. In case aggregation is desired or needed, ways to cope with this problem are development of optimal spatial units, spatial interpolation and sensitivity analysis taking into account different scales and zoning systems.

Mau et al. [2007] model impacts spatially by measuring attribute values of polygons. From these observations, they identify change in them over time and they derive what kind of event could have caused the impact.

SPATIAL POINT OF VIEW Previous studies have aimed at describing phenomena or impact. A distinction within these studies can be made based on the point of view of modelling. As described in Chapter 1, impact is defined by an impact source and a receptor affected by the source. Therefore, a main question when spatially modelling impact is whether to use the source or the receptor as a spatial point of view.

It is found that numerous studies use the source as a point of view for modelling impact or phenomena: what is the effect of a given source? What phenomenon does it cause? Or how many receptors does it affect? Numerous other studies approach

the concept from the receptor point of view: what is experienced at a receptor? How strong is the phenomena at the receptor? By which sources is it affected?

No studies or methods were found where both points of view are combined into one method or where the outcomes of the two are explicitly compared to each other. Also, no studies were found where the difference in spatial point of view is explicitly acknowledged.

In table 2.1, a summary of studies according to their spatial point of view is given.

Table 2.1: Summary table of spatial modelling point of view

Point of View	Type and/or Name	Reference
Source	Environmental Impact Significance Model	Antunes et al. [2001]
	Noise Model	Farcaş [2008]; Farcaş and Sivertun [2012]
	CO_2 Modelling for Infrastructure	Harris et al. [2011]
	Noise Effect Model	Kluijver and Stoter [2003]
	Odour Impact Model: AODM	Schauberger et al. [2001]
	Empirical Odour Model	Schauberger et al. [2012b,a]
	Odour Impact Model	Sironi et al. [2005]
	Gaussain Odour Dispersion Model	Smith [1993, 1995]
	Odour Model	Sówka et al. [2017]
	Odour Model (Gaussian Dispersion)	Úbeda et al. [2010]
Receptor	Compost Unit Model	Baas [2018]
	Noise Model: Dutch Standard Calculation Method	Dutch Ministry of Infrastructure and Environment [2012]
	Noise Model: TRANEX	Gulliver et al. [2015]

Within receptor based modelling, difference can be found in how the receptor is spatially modelled. The noise model described by Farcaş [2008]; Farcaş and Sivertun [2012] uses various ways to spatially describe the receptor (or as they call it *observer* or *receiver point*): as a cell in a regular grid; as irregular observation points combined with interpolation; as population points; as centroids of building facades. The noise model described by Gulliver et al. [2015] describe the receptor as a point one meter outside the centre of the building facade.

From the summary in table 2.1, it is interesting that all studies into odour modelling use the odour source as point of view.

THE BOUNDARY PROBLEM IN SPATIAL ANALYSIS Elements within the study area might be affected by elements outside it: the extent of the *area of impact* is larger than the extent of the *area of intervention* (the area of the spatial planning scenario, i.e.*study area* or *area of interest*). For the research case, this means that the impact of a source within the area of interest is defined by the receptors within it as well as outside of it. For impact at a receptor, the same principle applies vice versa.

[Stewart Fotheringham and Rogerson, 1993] describe the boundary problem, as well as possible solutions to it.

One solution is to incorporate points in the analysis which lie outside the study area (*domain D*) but still within reasonable distance (within a somewhat larger *domain D**) [Ripley, 1979], thereby increasing the number of points included in the analysis. Similarly, a solution can be to envelope the study area using a buffer zone, within which points are included in the analysis: the points in the buffer zone may have an effect on the points within the study area itself [Wong and Fotheringham, 1990]. These two similar approaches are applicable for geographical purposes.

Another approach to solve the boundary problem is to map the study area to a torus. This approach is only applicable to rectangular study areas and described in more detail by Ripley [1979]: all points on opposite edges are considered to be near and a grid of identical rectangles is created. However, this solution is not directly applicable for geographical purposes and therefore not further investigated for this research.

2.4 TEMPORAL FACTORS IN IMPACT MODELLING

TIME IN SPATIAL MODELLING Peuquet [2005] describes different challenges and methods to describe time in geographical software such as GIS and geographical databases. The focus lies on describing phenomena, having both geographical and temporal component. Temporal modelling of impacts is not specifically mentioned.

Similarly to space, Kelly et al. [2013] also identified four ways to deal with time in modelling. These are listed below:

1. *Non-temporal, static/steady state* models: a model without reference to time, only providing outputs for one specific state.
2. *Lumped discrete temporal/transient* models: a model providing outputs over a single period, for instance average value per year.
3. *Dynamic, quasi-continuous* models: a model providing outputs per time-step over a specific time period, for instance per day within a year.
4. *Continuous* models: a model providing output for each infinitely small time interval, often described by differential equations for theoretical modelling.

Mau et al. [2007] state that earlier, spatio-temporal modelling in GIS was done by storing data as snapshots of the state of the model at a specific moment in time. Later on, an event-based approach was explored where different parts in the model were dated separately. From this information, snapshots of states of the model at different moments in time could be composed. Eventually, events and objects were given the same status within spatio-temporal data models. Such models then allow for querying relationships between objects, events and processes.

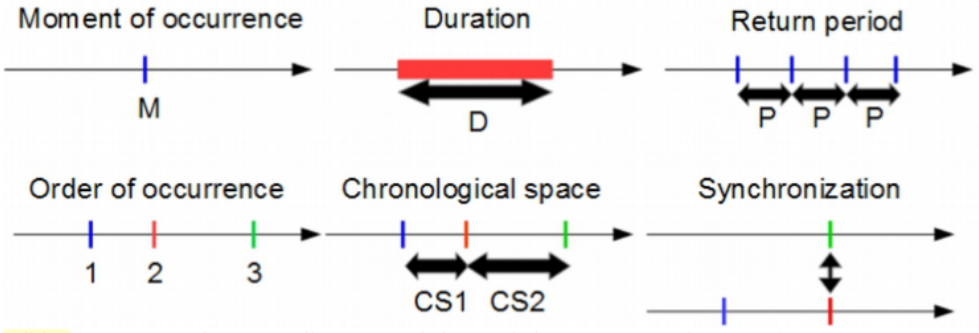
According to Miller et al. [2013], new capabilities and technologies allow for restricting temporal aggregation: frequent updates can for instance allow for modelling complex dynamics with greater sensitivity.

TEMPORALITIES OF EVENTS Gautier et al. [2017] use the concept of *temporality* to describe the temporal dimension of a spatio-temporal event. From research by Hewitt [1983]; Allen [1983]; DiBiase et al. [1992]; MacEachren [1994], they conclude that six temporalities can be used to describe the temporal dimension of a spatio-temporal event: the moment, duration and return-period of an event describe the event itself, while chronological order, chronological space and synchronization describe the temporal relation between events. In figure 2.2 a diagram is included to describe the concept of each temporality. Arnaud and Davoine [2009] also use the concept of temporalities. However, they do not incorporate synchronisation. In addition, they note that that return-period is an ambiguous concept, which can be interpreted as the probabilistic duration between events. They therefore introduce frequency, being defined as the number of occurrences of a phenomenon within a set period of time.

For visualisation, both Gautier et al. [2017] and Arnaud and Davoine [2009] use only five temporalities: moment, duration, frequency, chronological order and chronological space.

For modelling purposes for the case of this research, only the three temporalities describing events themselves are incorporated. The temporalities describing the

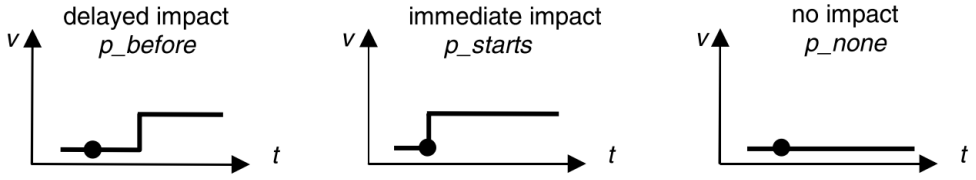
Figure 2.2: Temporalities of spatio-temporal events (from Gautier et al. [2017] based on Hewitt [1983]; Allen [1983]; DiBiase et al. [1992]; MacEachren [1994])



temporal relationships between multiple events are deemed redundant, since they can be derived from the other three temporalities in case needed.

TEMPORAL RELATION BETWEEN EVENT AND IMPACT Mau et al. [2007] derive different temporal event-impact relationships, building forth upon the possible temporal interval relations as defined by Allen [1983]. However, following the definition above, impacts must always start before or at the same time as the event and no event can end later than the corresponding impact. Figure 2.3 gives an impression on how temporal relationships between events and impacts are visualised by Mau et al. [2007] in accordance with the relationships defined by Allen [1983].

Figure 2.3: Temporal relationship between spatio-temporal event and impact (figure 2 in work by Mau et al. [2007])



In the definition of Mau et al. [2007], an event can either be durative, modelled as an interval, or punctual. An impact can be abrupt, an immediate change larger than a set threshold, or gradual, progressing over time and eventually larger than a set threshold. An event can cause an immediate impact, starting directly with the event, or a delayed impact, where the impacts starts on a later moment in time. Delayed impacts can be subdivided into threshold delays, occurring when an impact is only present in case of change larger and longer than a set threshold, and diffusion delays, occurring when event and impact are not spatially collocated resulting in a delay between the event and the occurrence of the impact.

Moreover, an impact can be lasting, when it does not change further. All these types of events, impacts and relationships can be described according to Allen [1983] temporal interval relations. They can be regarded as temporal primitives.

Impact can also evolve over time, where multiple primitives are combined to describe subsequent evolution. An example of this is an event causing an immediate increase of an attribute value followed by a gradual decrease of the same value.

2.5 AGGREGATION PRINCIPLES IN SPATIAL MODELLING

COMPENSATION IN AGGREGATION Antunes et al. [2001] propose a new spatial impact assessment method based on a case study assessing the environmental im-

pact of a proposed highway in central Portugal. In this procedure, aggregation of impact indicators can be done in two ways. As is also highlighted by Ferretti and Montibeller [2016], a factor in indicator integration is the level of compensation allowed: can bad performances on one indicator be compensated by good performances on another one. An example of this is whether a bad performance in human safety can be compensated by good performance on sustainability.

Miller et al. [2013] also states that the level of compensation allowed is leading when choosing an aggregation method. Similarly to the concept of compensation, Yager [1988] describes the concept of *andness* and *orness*. *andness* describes the extreme situation in which all criteria should be satisfied. *orness*, on the other side, is the situation where only one of the criteria has to be satisfied.

Miller et al. [2013] also describes the conceptual debate on compensation for sustainability issues in specific: *weak sustainability* implies that sustainability is reached when the net value of both natural and human-made capital is positive and therefore allows full compensation between them. *Strong sustainability* implies that natural resources are irreplaceable, and therefore allows no compensation.

FUNCTIONS FOR AGGREGATING INDICATOR SCORES According to Ott [1978], aggregation functions usually consist of three operations: firstly summation (i.e.adding indicator values), secondly multiplication (i.e.taking the product of some or all indicators values) and thirdly maximum or minimum operation (i.e.reporting the maximum of minimum indicator value). Ott [1978] also states that two problems can occur when aggregating indicator values: overestimation, when indicators are aggregated to a value exceeding a critical value without any of the individual indicators exceeding that value, or underestimation, similarly.

Antunes et al. [2001] propose two different methods for indicator aggregation.

1. The first method, from now on named *general aggregation*, is based on indicator weights, allowing for compensation. It is described by equation 2.1.

$$EI_j = \sum_{k=1}^{m} [w_k (\sum_{i=1}^{n} Q_{i,k} \frac{I_{k,i,j} - I_{k,i,0}}{IT_k}], \quad \forall j \subset J \tag{2.1}$$

2. The second method, from now on named *least favourable indicator aggregation*, is based on including the least favourable indicator, with no compensation allowed It is described by equation 2.2.

$$EI_j = min\{\sum_{i=1}^{n} Q_{i,k} \frac{I_{k,i,j} - I_{k,i,0}}{IT_k}\}, \quad \forall j \subset J \tag{2.2}$$

   For both equations the following applies: $\sum_{k=1}^{m} w_k = 1$; EI_j is the impact index of alternative j; m is the number of indicators; w_k describes the weight of indicator k; n is the number of classes in the environmental quality scale; $Q_{i,k}$ is the value of class i for indicator k; $I_{k,i,j}$ is the value to indicator k; $I_{k,i,0}$ is the value of indicator k when no alternative is implemented; IT_k is the total value of indicator k; and J described the set of planning alternatives.

Miller et al. [2013] presents four aggregation methods and equations to them. Of these four, the first method assumes full compensation, the second assumes no compensation and the latter two allow for intermediate approaches.

1. The first method Miller et al. [2013] mentions is Simple Additive Weighting (SAW). SAW is simple to use and understand. However, it assumes allowing full compensation and independency of preferences (whereas dependencies among attributes are often found in complex decisions and no relative importance of attributes can depend on others). Ferretti and Montibeller [2016] (table 2) states that, in case dependency among criteria cannot

be avoided, a more sophisticated aggregation method than a weighted sum method is needed. The SAW formula is shown in equation 2.3.

$$I_i = \sum_{j=1}^{n} w_j x_{ij}, \quad i = 1, ...m \tag{2.3}$$

where x_{ij} is the normalized indicator j for entity (geographic unit) i; w_j is the normalized weight of indicator j; n is the number of indicators; and m is the number of entities (i.e.geographic units).

2. The second method is called Weighted Product (WP) and assumes no allowance of compensation at all. The formula is shown in equation 2.4.

$$I_i = \prod_{j=1}^{n} (x_{ij})^{w_j}, \quad i = 1, ..., m \tag{2.4}$$

3. The third method addresses compensation in a more flexible way and is called Weighted Displaced Ideal (WDI). To use WDI, an ideal situation of the system has to be defined. WDI then identifies the system which is closest to this ideal.

$$I_i = [\sum_{j=1}^{n} w_j^p x_{ij}^p]^{1/p} \tag{2.5}$$

where $1 \leq p \leq \infty$ defines the distance metric: the way in which indicators are related. In case $p = 1$, the method is equal to the SAW method, in equation 2.3. In case $p =$ inf, the systems are compared to each other based on poorest performance over all indicators.

4. The fourth method is called Ordered Weighted Averaging (OWA) (developed by Yager [1988] and described in the work by Miller et al. [2013]) and is highly flexible regarding compensation. In OWA, weighted indicators are ordered by value, while a second *order weight* value reflects the position in this sequence of each single indicator.

$$I_i = \sum_{j=1}^{n} v_j z_{ij}, \quad i = 1, ..., m \tag{2.6}$$

where $z_{i1} \geq z_{i2} \geq ... \geq z_{in}$ is the sequence of n weighted indicators $(w_1 x_{i1}, w_2 x_{i2}, ..., w_n x_{in}$ arranged in weight descending order; v_j is a set of order weights, such that $0 \geq v_j \geq 1$ and $\sum_j v_j = 1$. The order weights determine how the logical operators are used on the indicator scores while aggregating. When choosing the order weights, it is determined whether the best system is defined based on its score on the least important indicator or, alternatively, on the most important one. Variation in order weights captures every possibility between them. The SAW method, can also be generated from OWA. To define order weights, several methods have been developed, some of which based on the *fuzzy set* concept [Miller et al., 2013].

In summary table 2.2,an overview is given of these aggregation methods and their main advantage and disadvantage. For this research, the choice was made to investigate the methods SAW and WP further. This choice was made since their equations are simple to apply and do not require further information such as an ideal situation or a counterfactual scenario.

NORMALISATION AND WEIGHTING METHODS When aggregating values, normalisation is needed. Optionally, relative weights can be assigned as well.

Table 2.2: Summary table of functions for aggregating indicator scores

Name & Equation	Advantage & Disadvantage	Reference
General aggregation (equation 2.1)	Advantage: direct comparison to counterfactual scenario; Disadvantage: elaborate equation	Antunes et al. [2001]
Least favourable indicator aggregation (equation 2.3)	Advantage: direct comparison to counterfactual scenario; Disadvantage: requires definition of least favourable indicator	
SAW (equation 2.3)	Advantage: simple; Disadvantage: assumes full compensation and no dependency amongst indicators	Miller et al. [2013]
WP (equation 2.4)	Advantage: simple; Disadvantage: allows no compensation at all	
WDI (equation 2.5)	Advantage: allows for intermediate compensation levels; Disadvantage: requires definition of ideal situation	
OWA (equation 2.6)	Advantage: allows for intermediate compensation levels; Disadvantage: requires definiton of order weights	

As far as normalisation of indicator values is concerned, Miller et al. [2013] mentions three methods: Z-score transformations, linear normalisation between thresholds and distance from the best and worst performer. Normalisation often requires definition of a reference point, reflecting judgement about ideal performance. The reference point should be able to reflect a sense of progress from bad to desired performance and should be realistic and meaningful [Miller et al., 2013].

Munda [2008] (box 5.2) describes five main normalisation techniques: standard deviation from the mean; distance from the group leader; distance from the mean; distance from the best and worst performer; and categorical scale.

Since no Gaussian distribution is expected in the impact values of this research, methods involving standard deviation or mean are not of use.

Miller et al. [2013] also describes weighting. Weights define the relative importance and are scale-free. A method to define weights is to choose them such that the monetary value of each indicator is expressed, which is often meaningful to decision makers and public involved. However, for social and environmental dimensions in particular, this approach can be misleading. Another method for assigning weights is *analytical hierarchy process* [Saaty, 1990], decomposing a multi criteria problem to sub criteria level. Decision makers are then asked to conduct pairwise comparisons between sets of sub criteria. Afterwards, a judgement matrix is composed expressing the relative weights of all sub criteria. Moreover, a method is described by Sakamoto and Fukui [2004]: *fuzzy structure modelling* allowing for modelling of ambiguous relationships in the calculation of indicator weights. This method is useful when one indicator reflects multiple objectives or when one objective reflects multiple dimensions.

Since involvement of actual decision makers is out of scope for this research, the choice was made to assign equal weights to all values to aggregate and thereby avoid the need to assign meaningful weights.

IMPACT INTEGRATION ON DIFFERENT SPATIAL SCALES Antunes et al. [2001] identify the problem that difference in spatial scales is often ignored when integrating impacts. This results in a situation where small scale impacts are absorbed by large scale impacts or the fact that small scale impacts are given the same weight and therefore introduce a bias in the evaluation. To overcome this problem, the study proposes an impact assessment procedure which defines different environmental components (i.e.noise) with their own impact indicators (i.e.affected area size, number of people, sensitivity of species) and different spatial scales (i.e.project, local, regional, national). The method aggregates only indicators of the same environmental components and presents results per component and per spatial scale separately.

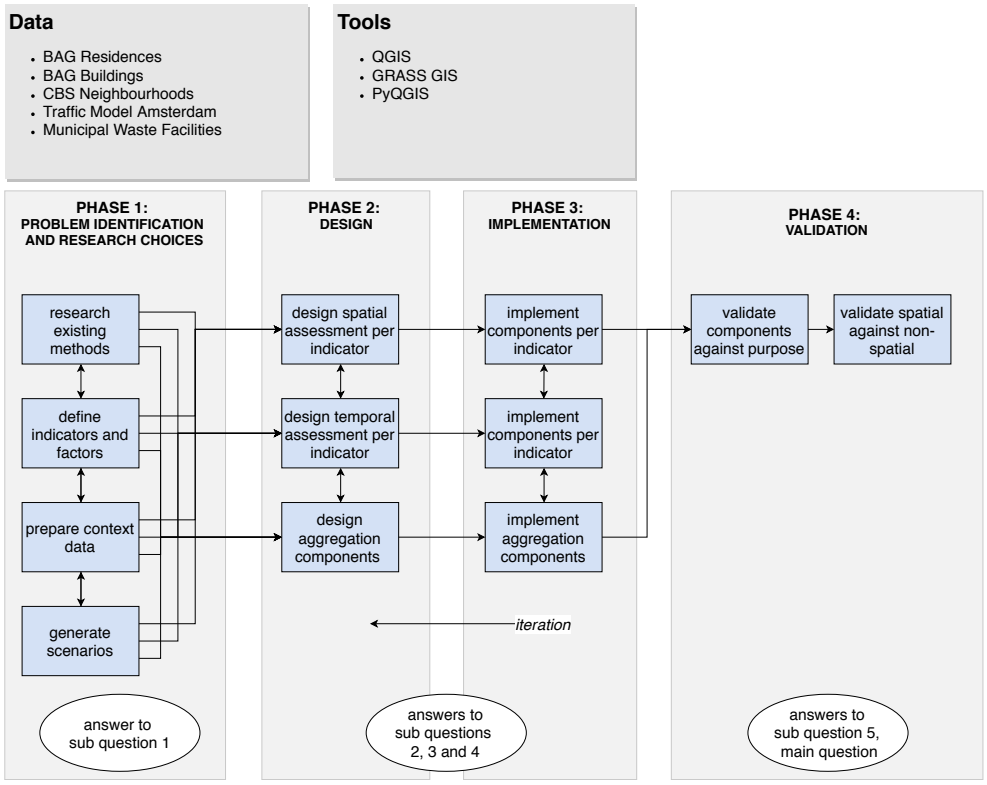
3 METHODOLOGY

This chapter describes the methodology followed in this research in order to arrive at an answer to the research questions stated in Chapter 1. All steps of the research methodology are described in detail and are explicitly linked to the research questions. The chapter ends with stating the tools and data needed for the research.

3.1 RESEARCH METHODOLOGY

The proposed research methodology is visualised in diagrams. It is divided into four phases: problem identification and research choices; design; implementation; and comparison of components. In figure 3.1 a simplified version of the research methodology is presented. In appendix A, the full diagram is included. For each phase, a short description of tasks and goals is given in the next paragraphs.

Figure 3.1: Simplified research methodology overview



PHASE 1. PROBLEM IDENTIFICATION AND RESEARCH CHOICES The core of this research phase is to clearly identify the research objectives and constraints. Moreover, it focuses on the link between this research project and related work. The goal of phase 1 is to have all information ready to be able to start designing the components of the assessment method. Phase 1 can be divided into four parallel and interlinked tracks:

1. *Research existing assessment methods*: research existing impact and planning assessment methods and the extent of their spatio-temporal possibilities; define purpose of the assessment method to design; identify non-spatial impact assessment principle for non-spatial comparison. Goal of this track is to know which methods for similar impact assessment cases have already been researched.

2. *Define impact assessment indicators and factors*: define the indicators for impact assessment; define factors to them and state level of allowed compensation for these factors; research existing methods to quantify the factors. Goal of this track is to exactly know which impacts and indicators are to be assessed, how they relate to each other and how they are quantified by other researches.

3. *Prepare context data*: define and obtain the context data; if needed perform conversion, cleaning and processing operations on them to make them usable for design and implementation. Goal of this track is to have all data ready to start designing the assessment method.

4. *Generate spatio-temporal planning scenarios*: define the components of the scenarios; research how they can be described spatially and develop them. The goal of this track is to arrive at realistic and usable spatio-temporal planning scenarios.

After phase 1, research sub question 1 can be answered.

PHASE 2. DESIGN Phase 2 is about the design of all components of the spatio-temporal impact assessment method. To achieve this, theoretical research and small practical experiments of possible approaches are used. The goal of this phase is to choose between possible approaches and to develop the individual components of the assessment method in detail in order to make them implementable in GIS. The phase can be divided into three parallel tracks:

1. *Design spatial assessment components per indicator*: choose or develop concepts to assess each indicator in spatial dimension; perform small practical experiments; design assessment per indicator; iterate if needed. Goal of this track is to develop the components of the assessment method per impact indicator in detail for the research case.

2. *Design temporal assessment components per indicator*: choose or develop concepts to assess each indicator, both in temporal dimension; perform small practical experiments; design assessment per indicator; iterate if needed. Goal of this track is to develop the components of the assessment method per impact indicator in detail for the research case.

3. *Design aggregation components for assessment*: choose or develop concepts for aggregation; perform small practical experiments; design aggregation approach; iterate if needed. Goal of this track is to develop the method components to apply the method to multiple criteria for the research case.

PHASE 3. IMPLEMENTATION In phase 3, the components of the assessment method designed in phase 2 are tested and implemented on the spatio-temporal planning scenarios developed in phase 1. The goal of phase 3 is to arrive at successful implementation of multiple spatio-temporal components of the impact assessment method. It can be divided into three parallel tracks:

1. *Spatial implementation per indicator*: implement the designed spatial assessment method components to the spatio-temporal planning scenarios per indicator; identify improvements. The goal of this track is to assess the scenario spatially on each indicator in sensible ways for the research case.

2. *Temporal implementation per indicator*: implement the designed temporal assessment method components to the spatio-temporal planning scenarios per indicator; identify improvements. The goal of this track is to assess the scenario temporally on each indicator in sensible ways for the research case.

3. *Aggregation implementation*: implement the designed aggregation components to the spatio-temporal planning scenarios; identify improvements. The goal of this track is to arrive at sensible multi indicator assessment methods for the research case.

Based on the outcomes of implementation, the choice can be made to iterate over (parts of) phase 2 and 3 one or multiple times. After the last iteration of phase 2 and 3, an answer can be given to research sub questions 2, 3 and 4.

PHASE 4. VALIDATION In phase 4, the developed spatio-temporal impact assessment components are validated: method components are validated against the purpose of the method and spatial outcomes are validated against non-spatial outcomes. The goal of phase 4 is to conclude whether a suitable spatio-temporal impact assessment method for the research case was found. It can be divided into two tracks:

1. *Validation against purpose*: validation of assessment method components against purpose of the method set in phase 1. The goal of this track is to describe the suitability of the method components.

2. *Validation against non-spatial*: present outcomes in non-spatial way; validate the added value of the spatio-temporal impact assessment method. The goal of this track is to describe the added value of the developed spatio-temporal assessment method compared to non-spatial principles.

After phase 4, an answer can be formulated to research sub question 5. Moreover, the answer to the main research question can be formulated.

3.2 TOOLS AND DATA

TOOLS Table 3.1 provides an overview of the three main tools needed for the research. To each tool, its purpose is stated, together with a link to additional information on the web.

DATA Table 3.2 provides an overview of the spatial data needed for the research. The two datasets from Basisregistratie Adressen en Gebouwen (Key Register Addresses and Buildings) (BAG) together with the CBS Neighbourhood data define the houses. The scenarios come forth from the Verkeersmodel Amsterdam (Traffic Model Amsterdam) (VMA) data and waste collection and handling facilities. The VMA data and the CBS Neighbourhoods are also used as separate input data for the method. In Chapter 5 the preparation of the datasets is described in detail.

WASTE COLLECTION SCENARIOS Two waste collection scenarios were designed. The spatio-temporal planning scenarios differ on three components: location and number of collection points, spatial routes along them and the temporal collection schedule. Table 3.3 gives an overview of these three components.

Based on the data defined in table 3.2, two spatio-temporal planning scenarios were developed. Concept sketches of these are shown in figure 3.2. These two scenarios are used for testing and implementation, as described in Chapter 5. In theory the assessment method is applicable to any scenario consisting of points and lines with a moment, duration and frequency to all features.

Table 3.1: Tools to be used

Tool	Purpose	Source
QGIS	Spatial data visualization and analysis: wide range of spatial processing tools to be used; visualisation of data, scenarios and impact assessment outcomes for intermediate inspection as well as final presentation; styling and cartographic layout of outcomes; QGIS interface provides access to GRASS GIS and PyQGIS tools as well	https://www.qgis.org/nl/site/
GRASS GIS	Spatial data analysis: network analysis to be used for generation of scenarios and network related assessment components; available via QGIS interface	https://grass.osgeo.org/
PyQGIS	Scripting language: Python environment within QGIS, to be used for combination of series of QGIS and GRASS GIS processing with freedom of using additional functions and variables; allows scripts to have QGIS layers as input and output	https://docs.qgis.org/testing/en/docs/pyqgis_developer_cookbook/

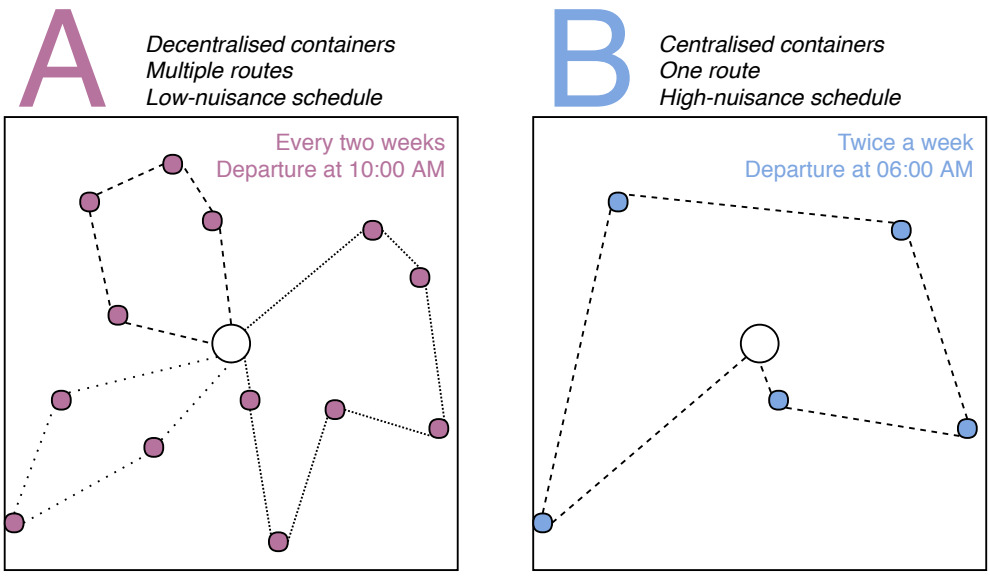
Table 3.2: Spatial datasets to be used: the Amsterdam city context

Dataset& Type	Purpose	Source
BAG Residences; Vector points: function, status, date	Define location and character of houses	[Dutch Kadaster via ESRI Nederland, 2017]
BAG Buildings; Vector polygons: function, status, date	Define location and character of houses	[Dutch Kadaster via ESRI Nederland, 2017]
CBS Neighbourhoods; Vector polygons: number of inhabitants [int], age distribution [%]	Define character of houses, spatial aggregation	[Centraal Bureau voor de Statistiek en Basis Registratie Kadaster (BRK), 2017]
VMA; Vector lines: load, capacity and speed per (non-) rush hour	Generation of scenarios and road calculations	[Municipality of Amsterdam and Department of Infrastructure Traffic and Transportation, 2015]
Waste Facilities; Tabular, Vector points	Generation of scenarios	[REPAiR, 2017; Municipality of Amsterdam, 2017]

Table 3.3: Spatial datasets to be used: planning scenarios

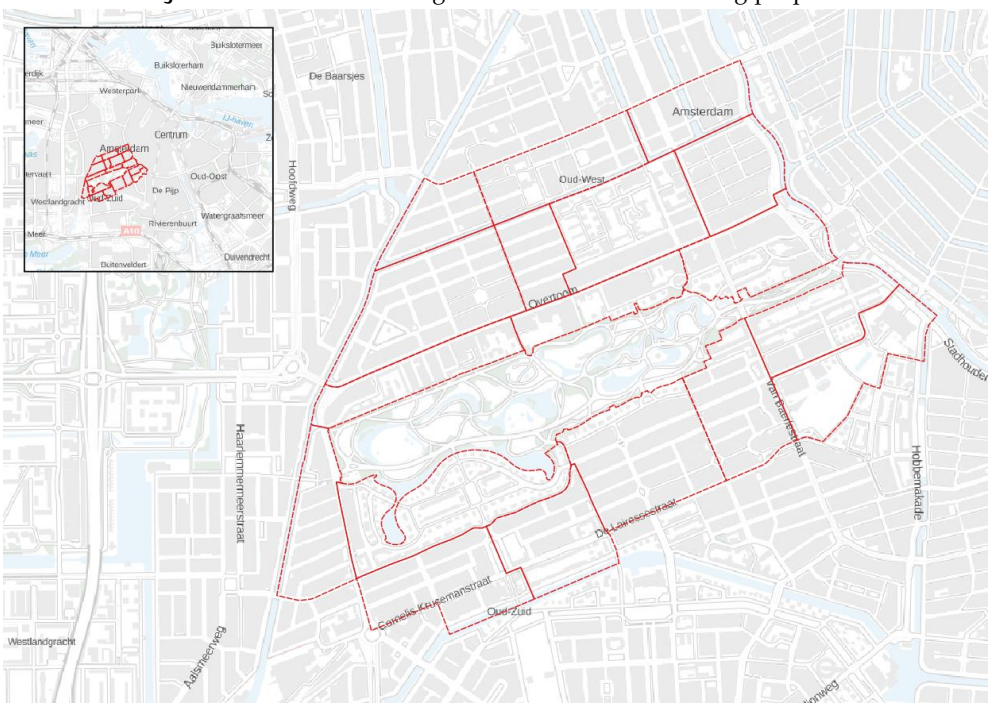
Datasets	Options	Type & Attributes
Containers	centralized and few; decentralized and many	Vector points
Routes	many short routes; few long routes	Vector lines
Schedule	low nuisance; high nuisance	Tabular: moment [datetime], duration [int], frequency [int]

Figure 3.2: Conceptual sketches of 2 waste collection system scenarios



TEST AREA A small geographical area was chosen for testing purposes, to allow for experimenting without high processing demands and to allow for large scale presentation of outcomes. This area is chosen for its representation of the city as a whole. Demands to the test area were that it should: cover both scenarios; cover multiple neighbourhoods; contain a congested road; be irregular in housing density; and contain geographical features which influence the accessibility of containers from houses, and therefore the amount of collected waste, such as water bodies. The chosen test area is located directly South-West of the city centre, around the Amsterdam Vondelpark. The area is shown in figure 3.3.

Figure 3.3: Test set area neighbourhoods used for testing purposes



4 DESIGN AND DEVELOPMENT

This chapter is concerned with the design of the spatio-temporal impact assessment method this research aims at developing. Firstly, the general concept of the method is elaborated on. Afterwards, quantification of the impact indicators and factors is described in detail, followed by a section on spatial aggregation and factor aggregation. In the end of this chapter, the components of the assessment method are defined such that they can be tested in practice.

4.1 PURPOSE AND CONCEPT OF THE METHOD

PURPOSE OF THE ASSESSMENT METHOD Following from challenges, questions, definitions and theoretical background described in Chapter 1 and Chapter 2, the purpose of the Spatio-Temporal Impact Assessment Method was formulated.

Firstly, the method should be able to assess impact on a spatial granularity which is coherent with the spatial granularity of the context data and scenario assessed. For this research case, scenario components are individual containers and routes as line segments between them. Context data for the case are individual houses and road segments within the city. Impact should therefore be calculated on similar granularity.

Secondly, the method should be able to assess the scenario in its whole extent. For the research case, this means that the method should work for the whole city of Amsterdam.

Thirdly, the method should be transparent in use for decision makers. Decision makers are expected to use the outcomes of the method to gain knowledge on the impact of a scenario as a whole as well as on individual features such as containers and houses. Based on the impact of or at individual features, decision makers can decide to make changes to a scenario for example by moving or eliminating containers with high nuisance impact. The outcomes should allow decision makers to reason backwards on relationships between sources and receptors which define the impact, and therefore avoid preliminary black box interpretation of outcomes. However, intuitive and simple presentation of the outcomes is needed to maintain overview: the method should balance information and simplicity.

DESIGN CHOICES Based on literature, numerous steps are relevant when assessing impact. For some steps, choices are made based on assumptions, expectations or following related work.

The choice was made to accumulate impact over a two week *time frame*, in accordance with the waste collection cycle in the three scenarios. In addition, it was chosen to treat temporal factors as attributes instead of using series of time frames.

The decision making *objectives* of the research case are Nuisance Reduction and Sustainable Planning.

Nuisance impact *indicators* are: the impact of *noise* on neighbouring inhabitants caused by emptying containers; the impact of *odour* on neighbouring inhabitants caused by the waste gathered at collection points when they are being emptied; the impact of *congestion* aggravation caused by collecting vehicles on other vehicles. Sustainable planning impact indicators are: the impact of CO_2 *emitted* by collecting vehicles on the environment; the impact of the extent to which organic *waste* is col-

lected by the system. The impact indicators were chosen based on work by Taelman et al. [2017] and based on Ministère de l'Écologie du Développement Durable et de l'Énergie: Inspection des Installations Classées [2012] stating that after noise, odour is the second cause for complaints about waste management facilities.

Each of the nuisance indicators is quantified using three *factors*: Intensity, Temporality and Affected Population. The sustainable planning indicators are quantified as Intensity only, only indirectly taking into account temporality and affected population. The intensity of the impact is quantified using existing methods. An overview of the relevant principles per impact intensity is included in table 4.1. The application of these principles is dependent on the spatial point of view. The temporality factor is based on moment in time, duration and frequency of the occurring impact. The affected population factor is based on the number of people affected by the impact.

Table 4.1: Calculation method for intensity factor per impact indicator

Impact	Principle	Source
Noise	Simple Noise Model	[Kluijver and Stoter, 2003; Dutch Ministry of Infrastructure and Environment, 2012]
Odour	Gaussian Plume	[Smith, 1993, 1995]
Congestion	VMA	[Municipality of Amsterdam and Department of Infrastructure Traffic and Transportation, 2015]
CO_2 Emission	Distance Based Method	[Harris et al., 2011]
Waste Collection	Walking Distance per Household	[Municipality of Amsterdam, 2016]

The choice was made to ignore *uncertainty* and *dependency* issues for this research.
To *normalise* values, linear normalisation between two thresholds is used.
In case values are aggregated, all of them will be assigned equal *weights*.

MAIN DESIGN QUESTIONS Two main questions for the design process which require extensive research are identified. Firstly, a question is what *spatial approach* is suitable to assess impacts. Two options were identified to assess impact:

1. Source Point of View: impact as a characteristic of each source
2. Receptor Point of View: impact as a characteristic of each receptor

Depending on the point of view and the impact indicator, the impact values can be assigned to different spatial types: vector points or vector lines, and placed at different locations. This design question influences the steps in which indicators are quantified. Figure 4.1 shows this conceptual difference in impact point of view.

Secondly, a question is what aggregation has to be used for spatio-temporal assessment, both of values (i.e.value aggregation) and in space (i.e.spatial aggregation). This question is related to the first question on spatial approach. In addition, it is related to the performance of the assessment method, its purpose and the visualisation of the outcomes. Chapter Chapter 2 has already elaborated on possibilities of aggregating values by means of aggregation equations. Figure 4.2 shows the concept of aggregation, both of values (figure 4.3a) and spatially (figure 4.3b).

CONCEPTUAL ASSESSMENT METHOD Based on the choices and questions mentioned above, a conceptual method was developed.

To model impact, the conceptual method defines the objectives, indicators and factors described in the design choices.

Figure 4.1: Conceptual diagram of 2 points of view for impact quantification

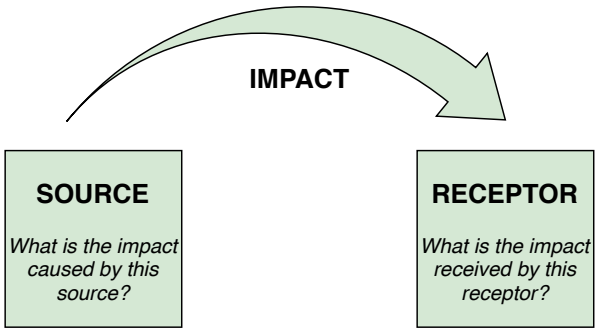
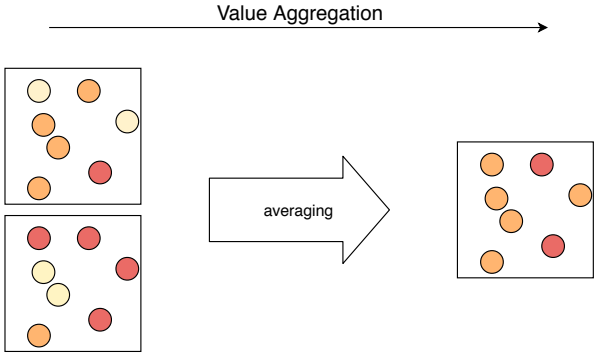
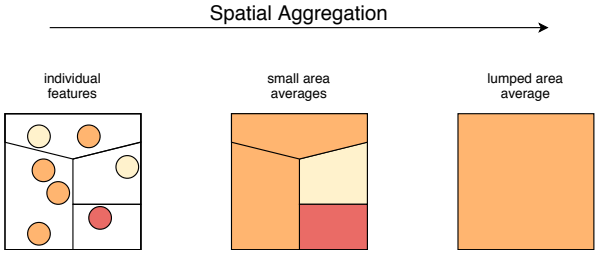


Figure 4.2: Conceptual diagram of value aggregation and spatial aggregation

(a) Value aggregation: aggregating multiple values belonging to same spatial entity into one value, example: averaging both values



(b) Spatial aggregation: aggregating values belonging to separate spatial entities within one area to area values, example: individual entities, small areas and lumped area



All factors (i.e.intensity, temporality and affected population as far as applicable) are quantified. Spatially, two approaches are taken in parallel: impact is quantified from both source and receptor point of view. To do so, existing calculation principles are used. As far as possible, the same principles are used for both the source and the receptor perspective to maintain coherence.

In order to allow for readable outcomes, aggregation may be used. Two types of aggregation are distinguished: value aggregation and spatial aggregation. With each aggregation step, information can be lost. On the other hand, some level of aggregation is often needed for reporting purposes [Miller et al., 2013] and to allow for convenient interpretation of outcomes.

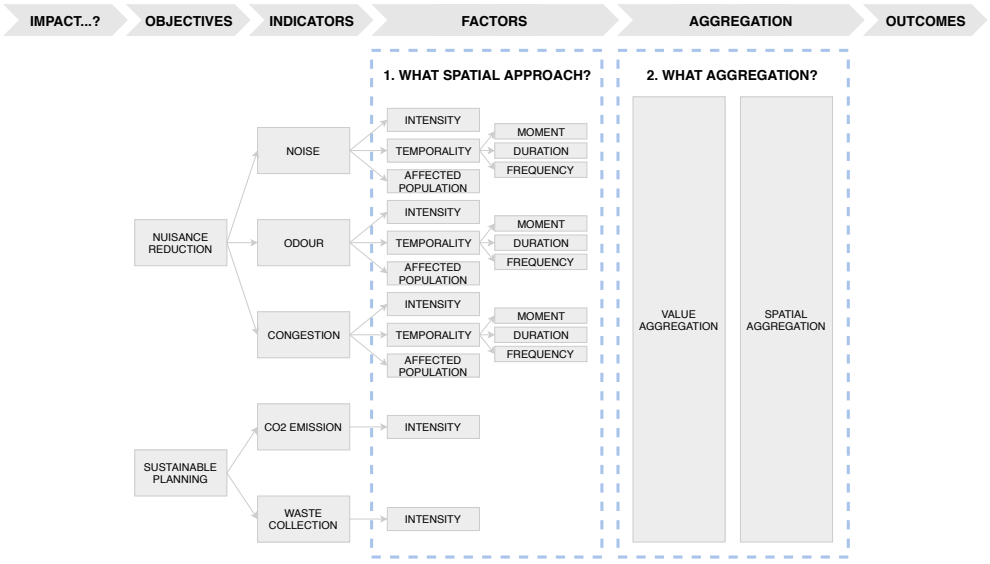
Value aggregation is aggregation of multiple values of the same spatial feature into one value for that feature. Numerous levels of value aggregation can be done: temporality aggregation means aggregating moment, duration and frequency into

one temporality value; factor aggregation means aggregating intensity, temporality and affected population into one indicator value; and indicator aggregation means aggregating impact indicators noise, odour, congestion, CO_2 emission and waste collection into one impact value.

Spatial aggregation is aggregation of values of the same type at multiple spatial features within an area to one value for the whole area. Possible spatial aggregation levels can for example be: aggregation to neighbourhoods; aggregation to city parts; aggregation to the whole city. Note that this last step of aggregating to city level corresponds with a non-spatial outcomes, since all spatial variance is lost. Next to choosing which area to aggregate to, a key question is what values are used: for example averages or totals.

The conceptual method is visualised in diagram in figure 4.4.

Figure 4.4: Diagram of the conceptual assessment method



The following sections elaborate on the components of the method and describe them specifically: how can they be quantified and are they indeed theoretically relevant within the purpose of the spatio-temporal assessment method.

4.2 SPATIAL MODELLING OF INTENSITY

4.2.1 Intensity Modelling for Noise

Numerous methods to spatially model noise are described in literature. In the following paragraphs, an overview of these is given. In the end, table 4.2 provides a summary. Based on this summary, a method is chosen for this research.

CNOSSOS-EU NOISE MODELLING *CNOSSOS-EU* is the standard method adopted by the European Union. Kephalopoulos et al. [2014] write that the method is still in development and describe its status in 2014.

CORTN ROAD TRAFFIC NOISE CALCULATION The United Kingdom Department of Transport has developed the method *Calculation of Road Traffic Noise* (CoRTN) [Department of Transport Welsh Office, 1988]. CoRTN includes equations for 1-hour noise levels and A-weighted noise levels (i.e. the noise level that is exceeded 10% of the time [Gulliver et al., 2015]. The CoRTN equations take into account traffic flow and speed, percentage of heavy vehicles, road gradient and surface,

slant distance and barriers between source and receptor, ground cover, angle of view and reflection of noise.

DUTCH STANDARD METHOD 1 AND 2 Noise impact can, according to Kluijver and Stoter [2003], be determined in GIS by combining the noise level information with information about location of receptors (i.e. people, animals and/or their activities) and also taking into account the receptor sensitivity to noise.

Kluijver and Stoter [2003] state that no universal noise mapping method does exist. However, there are two official noise calculation methods in the Netherlands: *Standard Calculation Method 1* and *Standard Calculation Method 2*. The first takes into account noise emission, distance from receptor to source, absorption of noise by the ground, wind, temperature and noise reflection. In addition, to that, the second method also takes into account noise obstruction by buildings. The methods are described in detail by Dutch Ministry of Infrastructure and Environment [2012]. Both Dutch standard methods are time consuming. Therefore, a third method was proposed by Kluijver: *Standard Calculation Method 11/2*.

According to Kluijver and Stoter [2003], a noise mapping method should consist of six steps: data collection, preparation, storage and querying; noise level computation; noise level accumulation, in case of multiple noise sources; noise contours determination; noise effect determination; and noise impact presentation. These six steps are defined in more detail in their study. The study stresses the importance of defining a desired level of detail in outcomes and therefore the need to avoid usage of data with different accuracy levels. Proper use of GIS in the process allows for quantification and visualization of noise impact. The interpolation method chosen to interpolate noise between calculation points is of influence on the outcomes. Also, it influences the efficiency of a method.

NOISE PREDICTION FOR SKÅNE REGION (SWEDEN) Farcaş and Sivertun [2012] developed a noise prediction model, using Skåne Region (Sweden) as case study. However, it is general and expected to work for new areas as well. The method is implemented as an extension in ArcGIS and coded in Visual Basics. It takes info account traffic flow, for both light and heavy vehicles, real speed, distance from noise receptor to road centre line, height of road surface, position, thickness and height of barriers, relative location of the receptor and ground type. It is based on the *Nordic Prediction Method* as described by Farcaş [2008].

The method consists of seven tools, amongst which *Noise calculation for roads and buildings*, *Noise calculation with population as receiver points* and *Population exposure to noise*.

Farcaş and Sivertun [2012] also mentions the concept of noise impact. Although based on spatial population exposure to noise calculations, the impact is displayed non-spatially in graphs.

TRANEX NOISE EXPOSURE CALCULATION Based on the CoRTN method, Gulliver et al. [2015] propose a method which models the exposure of addresses to traffic noise. The method is called *TRAffic Noise EXposure* (TRANEX), is implemented in programming language R using PostgreSQL and GRASS GIS functionalities and is open source. The method is designed to be transferable to cities other than the study area of Greater London, United Kingdom. In addition, it is designed to be efficient: feasible with limited computing resources. Although TRANEX is based on the CoRTN method, is has made some modifications. These are inclusion of treatment of noise source geometry, path distance, minor roads, road surfaces, tunnels and gradients along roads. In addition, CoRTN includes the European Noise Directive standards $L_{aeq,1hr}$, $L_{aeq,16hr}$ and L_{night} [European Parliament and Council of the European Union, 2002]. To convert the CoRTN L_{10} values to European L_{eq} values, the work by Abbott and Nelson [2002] was used.

TRANEX uses the noise receptors as a starting point for calculation: exposure assessment rather than noise mapping. To identify noise receptors, TRANEX uses a dataset of buildings with buildings heights. From this dataset, all buildings smaller than 15 m^2 were removed. Afterwards, a geometric centroid was created for each building. This centroid was moved to 1 meter from the facade outside of the building closest to the nearest road with traffic information available. This point now defines the noise receptor location. Subsequently, a circular buffer is created around a receptor and intersected with traffic source points. Straight lines are created between the receptor and each traffic source point within the buffer, intersecting with possible noise barriers and such.

OVERVIEW AND CHOICE Table 4.2 provides an overview of the noise modelling methods described and their feasibility for application in this research. The choice was made to model the noise level using *Standard Calculation Method 1* as defined by [Dutch Ministry of Infrastructure and Environment, 2012].

This choice was made for its feasibility and the fact that it is part of Dutch regulations. The method was simplified in order to make implementation in GIS feasible for the case. For this simplification, the choice was made to ignore the type of road surface, junctions, reflection of noise by vertical surfaces and the influence of air, soil and weather. However, a term was added to describe the noise shading of buildings between the receptor and source.

The equation to calculate noise levels defined in the method was rewritten to fit both modelling point of views: Receptor based and Source based. Noise receptors are centroids of houses (vector points). Noise sources are the containers (vector points).

Table 4.2: Summary table of spatial noise modelling approaches

Name	Feasibility	References
CNOSSOS-EU Noise Modelling	No: too elaborate	Kephalopoulos et al. [2014]
CoRTN Road Traffic Noise Calculation	No: too many unknown variables	Department of Transport Welsh Office [1988]
Dutch Standard Method 1 and 2	Yes: usable when simplified	Dutch Ministry of Infrastructure and Environment [2012]; Kluijver and Stoter [2003]
Noise Prediction for Skåne Region (Sweden)	Partly: too many unknown variables, identification of receptor interesting	Farcaş [2008]; Farcaş and Sivertun [2012]
TRANEX Noise Exposure Calculation	Partly: method too elaborate, identification of receptor interesting	Gulliver et al. [2015]

RECEPTOR BASED NOISE MODELLING The equivalent noise level L_{eq} ([dB])at a receptor can be calculated using equation 4.1.

$$L_{eq} = E - D_{distance} - D_{building} \tag{4.1}$$

Where E is the noise emitted by the source ([dB]), set to a default value of 100, and where $D_{distance} = 10\log(d)$, describing the decrease of noise over a distance d ([m]).

$D_{building}$ can be calculated in a general way or in a specific way. Generally, the term can be calculated based using equation 4.2.

$$D_{building} = d * \rho_{buildings} * c \tag{4.2}$$

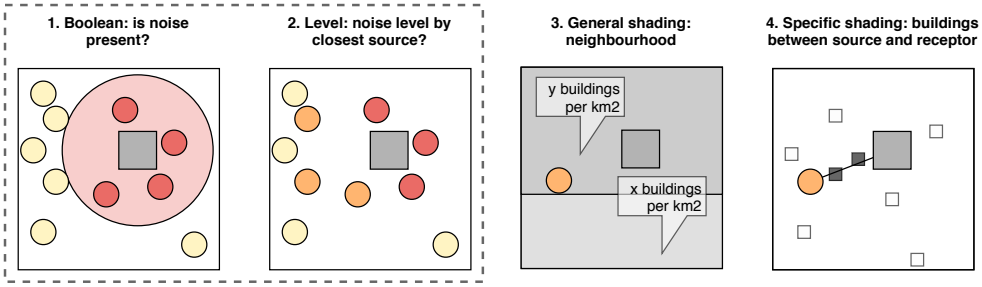
Where $\rho_{buildings}$ is the average number of buildings per meter distance and c is a constant defining the decrease of noise per building ([dB]). c is set to a default value of 3dB: each buildings decreases the noise level by half.

For the number of buildings, an assumption can be made. The default is set to 0.02 building per meter (20 buildings per kilometre distance). Another option is to calculate the building density per neighbourhood.

For the specific method of calculating $D_{building}$, a line has to be drawn between each noise source and receptor couple. The shading at the location of the receptor is defined by the number of buildings the line crosses: $buildings * c$.

Within the possibilities of these formulas and assumptions, four possible noise modelling methods in GIS were defined, enumerated from simple to more elaborate. In figure 4.5, these steps are shown in concept. The steps within the dotted line were implemented for this research.

Figure 4.5: Diagram of the four conceptual noise modelling possibilities from simple (1) to elaborate (4); step 1 and 2 were implemented for this research



SOURCE BASED NOISE MODELLING To define the noise impact caused by a source, the choice was made to use buffer zones around the source. Buffers can be generated for different noise thresholds. The radius of the buffer ([m]) can be calculated using equation 4.3.

$$r = 10^{E - L_{eqThreshold} - D_{building}} / 10 \tag{4.3}$$

Where E is the emitted noise level ([dB])$L_{eq-threshold}$ is the threshold noise level of the buffer zone ([dB]). $D_{building}$ can be calculated generally using equation 4.4.

$$D_{building} = 10^{(E - L_{eqThreshold})/10} * \rho_{buildings} * c \tag{4.4}$$

Similar methods can be used to model the impact of a source, but for sources only applied for level 1.

4.2.2 Intensity Modelling for Odour

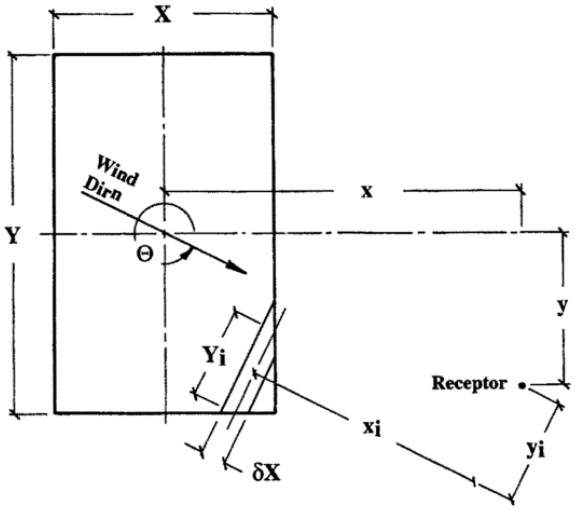
For odour modelling, numerous methods were found as well. They are described below and summarised in table 4.3, before the choice for a method is made.

EMPIRICAL ODOUR MODELLING In research by Schauberger et al. [2012b,a], a method for Empirical Odour Modelling is described. It is meant for modelling odour nuisance to residential areas caused by livestock buildings. It is simple and

quick but not very detailed. To model the odour nuisance, it takes into account odour emission flow rate of the source, relative wind direction frequency and the probability of a set odour threshold exceeded. The method is only spatial to a limited extent: calculating the distance needed between source and receptor per wind direction frame in order to avoid exceeding a defined odour probability threshold.

GAUSSIAN PLUME MODEL Smith [1995, 1993] describe the Gaussian Plume Model for Odour modelling, called *STINK*. However, it is meant for odour from areal sources of finite size. The main factors the method takes into account are concentration of odour at the source, height of the source, distance from source to receptor, crosswind, vertical spread of the odour plume, aerodynamic roughness of the terrain and atmospheric stability. The proposed method calculates odour concentration at specified points downwind via equations. In figure 4.6, a sketch of the spatial variables defined by source and receptor is given.

Figure 4.6: Definition sketch for areal source (figure 1 in work by Smith [1995])



IMPACT PATHWAY FOR ORGANIC WASTE ODOUR For odour caused by organic waste specifically, Marchand et al. [2013] proposed a pathway to impact assessment. Reason for this is that they identified a gap in *Life Cycle Assessment* (LCA) of not taking into account an impact category for odour. The research defines odour impact as the level of discomfort to human beings. Also, it defines the need for spatial differentiation in doing so: a local site-dependent approach. This choice is motivated by the identification that odour is a local impact which raises the need to take into account emission characteristics, environmental distribution, background concentrations and receptor sensitivity.

The proposed site-dependent approach consists of five steps: characterisation of emission, quantity, time, frequency, emission compartment, location and source type; fate analysis compound distribution between environmental compartments, dilution immobilisation, removal and degradation; exposure analysis characteristics of the impacted environment, increase of environmental and background concentrations; effect analysis no-effect concentration and critical concentration; and damage analysis type and magnitude of the impact.

Although the method by Marchand et al. [2013] takes into account site-dependent factors and variables, it does not address impact in a spatial differentiated way.

OVERVIEW AND CHOICE In table 4.3 an overview is given of the described methods and their feasibility. The choice was made to model odour by using a simplified version of the Gaussian Plume Model method described by [Smith, 1993, 1995].

Table 4.3: Summary table of spatial odour modelling researches

Name	Feasibility	References
Empirical Odour Modelling	Yes: simple method, variables known, however only spatial to limited extent	Schauberger et al. [2012a,b]
Gaussian Plume Model	Yes: simple method, variables known or can be assumed	Smith [1995, 1993]
Impact Pathway for Organic Waste Odour	No: not spatial	Marchand et al. [2013]

Simplification was achieved by choosing to ignore the spreading of odour in vertical direction.

Parts of the method by Schauberger et al. [2012a,b] were explored as extension to the Gaussian Plume Model. This method incorporates the relative frequency of wind directions into odour modelling for a limited set of wind direction frames. Including fixed wind direction frames into the method allows for the choice to also ignore cross-wind spreading of odour as described by [Smith, 1993, 1995].

The equation to calculate odour levels was again rewritten to fit calculation of odour for both receptor and source point of view. Odour receptors are centroids of houses (vector points) and odour sources are containers (also vector points).

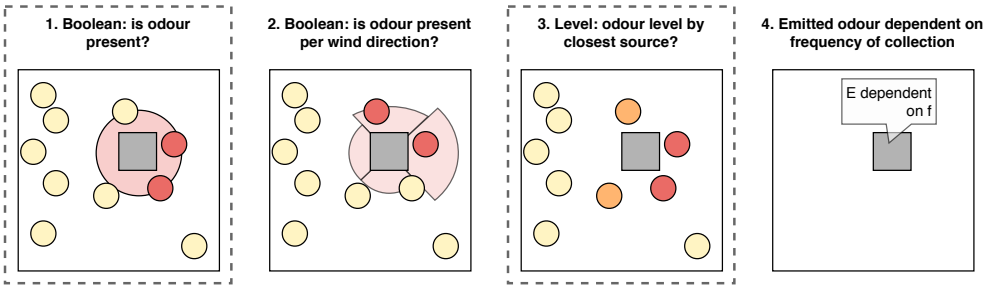
RECEPTOR BASED The odour concentration C ([$OU_E/s/m^2$]) at a receptor can be calculated using equation 4.5.

$$C = E/(\pi * 0.04422 * d^{1.5563} * u) \tag{4.5}$$

Where E is the emitted odour concentration, set to a default value of 236 (59 OU_E/s * 4 m^2 of emitting surface, following Sironi et al. [2005]) ([$OU_E/s/m^2$]). d is the distance to the source ([m]) and u is the wind speed ([m/s]).

Within the possibilities of these formulas and assumptions, four possible odour modelling methods in GIS were defined, enumerated from simple to more elaborate. In figure 4.7, these steps are shown in concept. The steps within the dotted lines were implemented for this research.

Figure 4.7: Diagram of the four conceptual odour modelling possibilities from simple (1) to elaborate (4); step 1 and 3 were implemented for this research



SOURCE BASED To define the odour impact caused by a source, buffer zones are used. Buffers can be generated for different noise thresholds. In addition, difference can be made between wind direction frames. The radius of the buffer ([m]) can be calculated using equation 4.6.

$$r = (E/(C * \pi * u * 0.04422))^{0.64255} \tag{4.6}$$

The same steps for elaborating modelling methods apply as for receptor-based modelling of odour, but for sources, only level 1 was applied in this research.

4.2.3 Intensity Modelling for Congestion

For spatial congestion modelling, no elaborate research was performed into possible methods. This was done since the road dataset VMA suggests a simple and to the point method, which is therefore the obvious choice for the project. This approach is to use the congestion level, calculated during data preparation, based on the capacity and load for each road segment for the morning (07:00 to 09:00), evening rush hours (16:00 to 18:00) and regular hours. If case a waste container is located along a congested road segment, congestion impact is caused by the container (vector point) on drivers (visualised as vector lines: they drive on the same road segment). This congestion level per road segment can fit both source and receptor based impact modelling.

RECEPTOR BASED CONGESTION MODELLING To calculate the congestion level, equation 4.7 can be used.

$$C = (L_{passengercar} + 2 * L_{truck}) / c_{passengercarequivalent} \tag{4.7}$$

Where L is the load of the road segment, for either passenger cars or trucks, and c is the capacity of the segment in passenger cars. Municipality of Amsterdam and Department of Infrastructure Traffic and Transportation [2015] assumes a single truck to be double the load of a car. A road segment is assumed congested when its congestion level is over a threshold. The variables for calculation depend on moment of day: morning rush hours, evening rush hours and general hours.

To determine the congestion nuisance spatially, first it should be determined whether the road is congested or not. When it is congested, a 10 meter buffer is drawn, to represent the direct neighbourhood of the segment. If containers fall within this buffer, they can cause congestion nuisance to the other vehicles on the segment when they are emptied. It was chosen to use a buffer instead of calculating the closest container and check whether it is 10 meters or less to make the calculations more consistent in steps to the source based congestion modelling, which also uses a buffer.

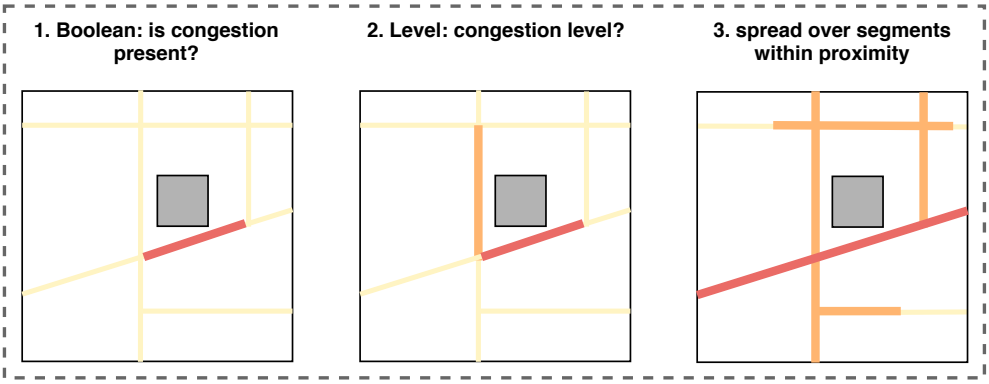
Note that to make the receptor based congestion model more accurate, it should be acknowledged that congestion nuisance occurs at the road segment itself, but also to adjacent road segments at locations in proximity. The longer the nuisance lasts, the further along the network the nuisance spreads.

To keep application simple, it is assumed that emptying a container takes 2 minutes. Within these two minutes, congestion spreads over a network distance of $max_{speed} * 1000 * (2/60)$ meters, where max_{speed} is the allowed speed in km/h, converted to m/h by multiplying with 1000 and where 2/60 represents the duration of 2 minutes in hours. Note that this approach ignores the fact that actual speed is in practice often lowered by congestion.

Within the possibilities of these formulas and assumptions, three possible congestion modelling methods in GIS were defined, enumerated from simple to more elaborate. In figure 4.8, these steps are shown in concept. The steps within the dotted lines were implemented for this research.

SOURCE BASED CONGESTION MODELLING For source based congestion modelling, a very similar method can be applied: around each container, a buffer of 10 meters has to be drawn. In case this buffer overlaps with any congested road (i.e.the congestion level of a container is not caused by the closest segment but by the most congested segment within direct proximity), the container causes congestion nui-

Figure 4.8: Diagram of the four conceptual congestion modelling possibilities from simple (1) to elaborate (3); all steps were implemented for this research



sance. The congestion level and the load of the road with the highest congestion level within the 10 meter buffer is inherited by the container.

The same steps of elaboration of the method apply to source based modelling as to receptor based modelling, but this research only applies level 1 and 2.

4.2.4 Intensity Modelling for CO_2 Emission

For CO_2 Emission it is relevant to model where the emission is caused. However, receptor based modelling is irrelevant, since CO_2 particles in the atmosphere affects every location in the world. Therefore, spatial CO_2 emission modelling is addressed from a source point of view only. Sources are represented by road segments (vector lines). From the receptor point of view, the total amount of CO_2 emitted by the scenario might provide useful impact information.

SOURCE BASED CO_2 MODELLING The mass of CO_2 emitted by the truck driving along a segment of the route can be calculated using equation 4.8. This formula follows work by Harris et al. [2011]. It assumes the vehicle to be a 5 tonne lorry driving at a speed of 54 mph (approximately 90 km/h).

$$M = d * (0.001167 * L + 0.15797) * f_{speed} * 2.63 * frequency \tag{4.8}$$

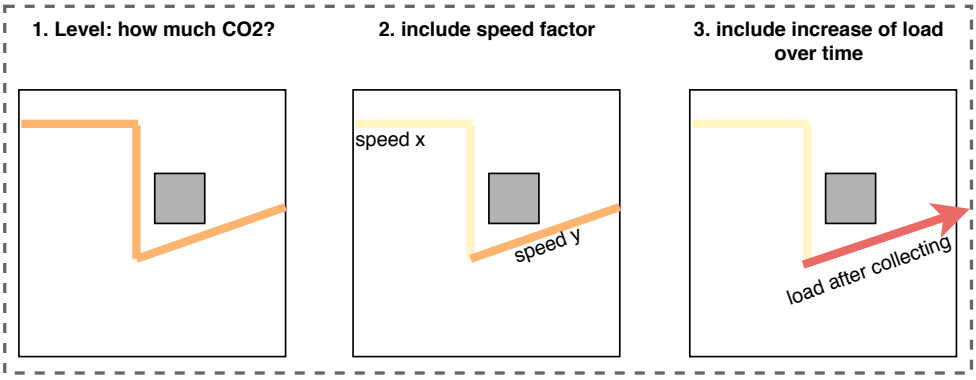
Where d is the distance (length) of the segment ([km]) and L is the load percentage, with a value ranging from 0 (empty) to 100 (full). The last constant, 2.63 kg/litre, is the fuel conversion factor. This number assumes the fuel to be diesel. The term $0.001167 * L + 0.15797$ describe the fuel consumption per kilometre, which are linearly related. This relation was found by extrapolating known fuel consumption numbers for 5 tonne lorry weight laden values of 60, 75 and 90 (table 3 in Harris et al. [2011]). The factor f_{speed} describes the factor with which fuel consumption is different dependent on the vehicle speed. Harris et al. [2011] provides factors describing the difference in fuel consumption for vehicles driving at 45, 36 or 30 mph (approximately 70, 60 and 50 km/h) compared to vehicles driving at 54 mph ([Harris et al., 2011], table 4). Based on these numbers it is assumed that $f_{speed \geq 80km/h} = 1$, $f_{80km/h > speed > 50km/h} = 0.94$ and $f_{speed \leq 50km/h} = 0.97$. By including the $frequency$, the total mass of CO_2 emitted within a 14 day period is calculated.

Note that in order to compare different segments to each other and for visualisation purposes, it makes sense to divide the CO_2 emission values of a road segment by its length. This simplifies the calculation by taking out the variable d from equation 4.8.

Within the possibilities of these formulas and assumptions, three possible CO_2 emission modelling methods in GIS were defined, enumerated from simple to more

elaborate. In figure 4.9, these steps are shown in concept. The steps within the dotted lines were implemented for this research.

Figure 4.9: Diagram of the four conceptual CO_2 emission modelling possibilities from simple (1) to elaborate (3); all steps were implemented for this research



As a measure of impact from the receptor point of view, the total amount of CO_2 per scenario can be accumulated. This allows for comparison of the scenarios as far as CO_2 is concerned, without it being spatially variant.

4.2.5 Intensity Modelling for Waste Collection

It is assumed that the amount of collected waste is highly correlated to the the extent to which containers are accessible for inhabitants. For spatial accessibility modelling, the obvious choice is to follow the Municipality [Municipality of Amsterdam, 2016] in their way of describing customer service: the return trip walking distance from house to container, measured in kilometres per household per year. Municipality of Amsterdam [2016] assumes organic waste is offered twice a week, due to its odour.

Municipality of Amsterdam [2016] finds a maximum walking distance of 29.1 km/household/year. This value is used to calculate the threshold defining whether a container is accessible from a house or not: 29100 metres spread over 52 weeks, walking back and forth twice a week gives a maximum distance of $29100/(52 * 2 * 2) = 140m$.

Waste collection sources are containers, while its receptors are centroids of houses (both vector points).

RECEPTOR BASED WASTE COLLECTION MODELLING For receptor based waste collection modelling, a 140 m buffer around a house can be calculated. Any container within this buffer is accessible in case Euclidean distances are used. In case network distances are used, the network distance to any container within the buffer of the house can be calculated to find whether one of them is within the accessibility threshold.

An accessibility rate can be calculated using equation 4.9.

$$A = (140 - d)/140 \tag{4.9}$$

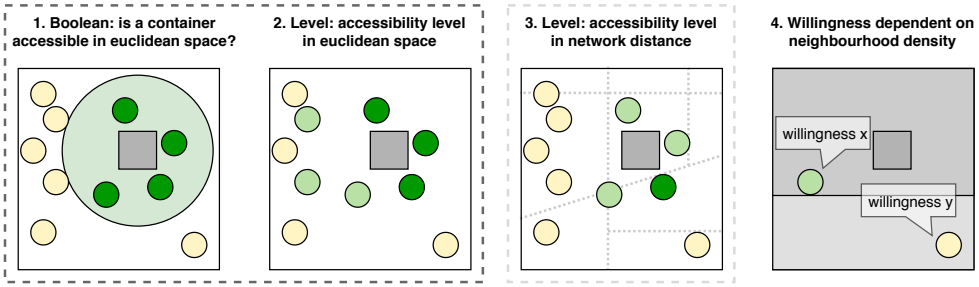
Where d is the distance to the container, either Euclidean or via the network. To calculate the mass of waste a household is expected to drop in a container within a period of 2 weeks, equation 4.10 can be used.

$$M = A * \frac{92}{26} * n_{people} * f_{willingness} \tag{4.10}$$

Where 92 represents the value of 92 kg or organic waste produced per inhabitant per year, divided by the number of two week periods within a year 26 (52 weeks / 2), n_{people} is the number of people in the household and $f_{willingness}$ is the willingness of the household to offer organic waste separately, normalised to values from 0 (not willing) to 1 (fully willing). Meijer [2018] states that nationally, approximately 50% of organic waste is collected separately. However, the willingness in densely populated areas is often lower. It is therefore assumed that a default willingness value of 0.3 is realistic for the city of Amsterdam. However, values can also be made dependent on the the building density of neighbourhoods.

Within the possibilities of these formulas and assumptions, four possible waste collection modelling methods in GIS were defined, enumerated from simple to more elaborate. In figure 4.10, these steps are shown in concept. The steps within the dotted lines were implemented or tested for this research.

Figure 4.10: Diagram of the four conceptual waste collection modelling possibilities from simple (1) to elaborate (4); steps 1 and 2 were implemented for this research, step 3 was tested



SOURCE BASED WASTE COLLECTION MODELLING For source based waste collection modelling, the same equations and principles account. Around a container, a 140 m buffer covers all houses which have access to the container over Euclidean distance. In addition, GIS tools are available to define which parts of a network can be reached within 140 m from a given point. A convex hull can be used to find all houses for which the container is accessible along the network. Besides that, accessibility values can be calculated for all accessible houses, summing up to an overall accessibility value of the container. Similarly, the overall mass of collected waste over a 2 week period by the container can be found, with a maximum of its total capacity, as described in the section on normalisation.

Similar steps and extensions to make the spatial waste collection model more accurate apply as defined to the receptor based modelling. From source point of view, implementation is done at level 1, while tests are performed at level 3 as well.

4.3 SPATIAL INCORPORATION OF TEMPORALITIES

As stated before, geographical phenomena have a temporal dimension as well as a spatial dimension: they are spatio-temporal. If the world is described in a spatio-temporal model, spatial planning scenarios can be represented by spatio-temporal events. To spatio-temporal events the temporalities moment, duration and frequency apply.

Spatio-temporal events can cause spatio-temporal impacts, to which the same temporalities apply. As already elaborated on in the design choices, it is chosen to assess the nuisance impact indicators noise, odour and congestion using a temporality factor. This temporality factor consists of three sub factors: moment, duration and frequency. The temporality factor can be related to impact significance.

For the sustainable planning impact indicators CO_2 emission and waste collection, the choice was made not to include temporality as a separate factor: for those indicators the temporal dimension is already implicitly addressed within the intensity factor.

This can be illustrated by the fact that the amount of CO_2 emitted is dependent on spatial factors such as route length and speed, indirectly describing duration. The CO_2 emission impact is not aggravated by the moment at which this happens. Moreover, its frequency can directly be incorporated in the total amount of emitted particles.

For Waste Collection, similar statements can be made: moment in time does not influence the accessibility of the containers, since the relative location of source and receptor are static, as well as the transport between them (i.e.transport by foot or bike is assumed, which is not affected by for example rush hours). Moreover, duration and frequency define the distance threshold for intensity modelling.

TEMPORAL WEIGHT CURVES For all three temporalities and all three nuisance impact indicators, temporal weight curves were made. These curves describe the weight of the impact (on the y-axis, normalised scale) as a function of time (on the x-axis, with its scale in steps of minutes, hours or days). The weight curves are shown in image 4.11.

The moment curve for noise is based on the *Lden* concept, which makes distinction between the noise during the day, evening and night. The Dutch regulations define day as the period from 07:00 to 19:00, evening from 19:00 to 23:00 and night from 23:00 until 07:00 [Dutch Ministry of Infrastructure and Environment, 2012]. The duration and frequency curves are based on assumptions.

For the moment curve of odour, it was found that Schauberger et al. [2001] conclude that the probability of odour sensed by receptors has a clear peak between 19:00 and 20:00. From 16:00 to 22:00 the probability exceeds the 2-year average. Huey et al. [1960] on the other hand defines the PM hours as the most conducive to odour nuisance. The duration curve is based on research by Nicell [2009], which is using averaging periods of 10 minutes and 1 hour for odour. It is described that complaints about odour often start to be made after a period of 10 minutes of exposure to moderate odour levels. In addition, the research mentions odour during 8 continuous hours as an upper threshold, although it stresses that further research into the validity of this threshold is still required. The frequency curve is composed based on assumption.

The moment curve of congestion is directly related to the dataset provided by the Municipality of Amsterdam and Department of Infrastructure Traffic and Transportation [2015], with morning rush hours from 07:00 to 09:00 and evening rush hours from 16:00 to 18:00. The duration and frequency curves are based are assumption based.

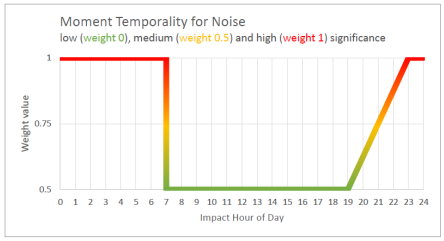
To calculate the temporality factor value of an impact indicator, the corresponding moment, duration and frequency value are aggregated. Within this aggregation, no compensation of one factor for another is allowed. All three values are chosen to have equal weights. Equation 2.4 describing aggregation method WP (elaborated on in Chapter 2) shows how the temporality value can be calculated from the the moment, duration and frequency value [Miller et al., 2013].

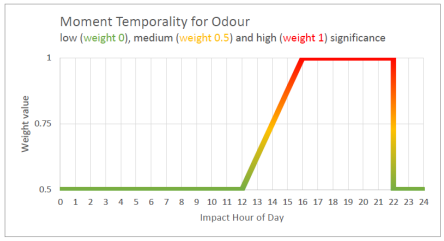
The weight curves make sure that an aggregated temporality factor value can only be 0 if at least one of the values is 0: if the impact occurs 0 times per two weeks; if the duration of the impact is 0 minutes (or less than 10 in case of odour impact); if the moment in case of congestion impact occurs outside congestion hours.

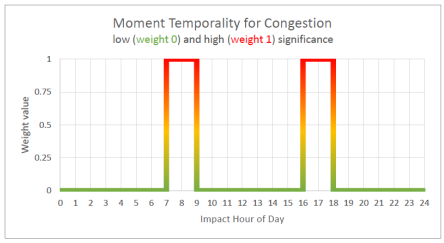
SYNCHRONISATION OF IMPACTS The choice was made to ignore the effect of multiple nuisance impact sources of the same type at the same moment in time on a receptor (i.e.multiple containers producing noise received at a single house at 12:00).

Figure 4.11: Temporal weight curves for indicators Noise, Odour and Congestion: impact weight as a function of time

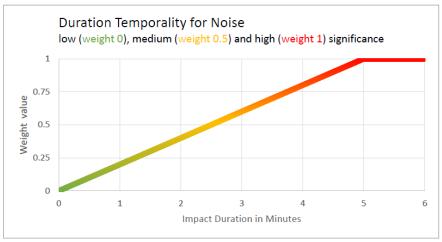
(a) Moment

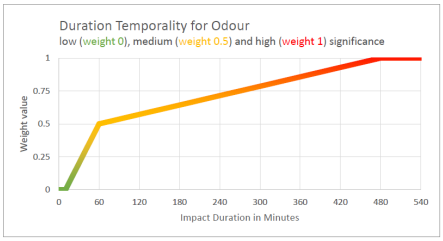


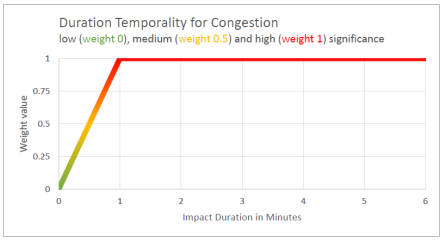




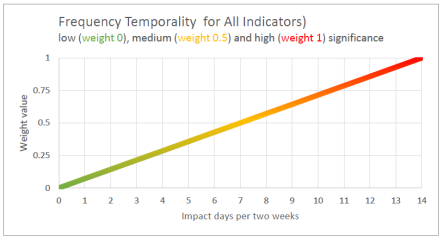
(b) Duration







(c) Frequency



This eliminates the need to aggregate for example noise values of different sources in the spatio-temporal model.

This choice was made since the chance of multiple impact sources of the same type at the same moment in time at the same location is minimal: the impact noise and congestion are limited in duration, whereas the impact odour is limited in space. Moreover, the different waste collection events of one scenario always follow one another.

4.4 SPATIAL MODELLING OF AFFECTED POPULATION

The third factor for quantifying impact is the affected population factor, describing the number of people affected by the impact. For the research case, spatial variance of affected population is relevant when quantifying nuisance impact Noise, Odour and Congestion.

For CO_2 Emission, the affected population is constant for every scenario: it is not a local impact but a global one. The choice to exclude the affected population factor for CO_2 is essentially similar to the choice not to model CO_2 Intensity from receptor perspective.

For Organic Waste Collection Impact, the number of people is inherent to the calculation of the Intensity: per house, the number of people defines the amount of organic waste.

4.4.1 Affected Population Modelling for Noise and Odour

For noise and odour, the receptors are houses. The affected population modelling is therefore done per house.

Within the data, information is available on the number of inhabitants per house and the neighbourhood percentage of people per age category (i.e.percentage of children (14 years and younger) or elderly people (65 year and older)). This information can be used to model the affected population factor in a straightforward way. Equation 4.11 can be used to calculate the affected population factor P per house.

$$P = I * (\frac{p_c * w_c}{100} + \frac{p_e * w_e}{100} + \frac{100 - p_c - p_e}{100}) \tag{4.11}$$

$$P = I * (\frac{p_c + p_e + 100 - p_c - p_e}{100}) = I \tag{4.12}$$

where I is the number of inhabitants of the house, p is the percentage of vulnerable inhabitants (children c, 14 years and younger, or elderly people e, 65 years and older) and w is the weight assigned to each vulnerability category and should be 1 or higher. Default values of w_c and w_e are 1, setting P to be directly equal to I for the default case (equation 4.12).

From simple to elaborate, the spatial affected population factor can be modelled in GIS using the steps described below. This research only applies level 1.

1. What is the number of inhabitants? All inhabitants counting equally, summing up to the affected population factor
2. Use weight values higher than 1 for vulnerable age categories

4.4.2 Affected Population Modelling for Congestion

For congestion, receptors are road segments in proximity to a container.

The number of receptors affected can be calculated by using the passenger car and truck loads (provided in vehicles per hour). The affected population can be calculated using equation 4.13. This equation uses the default duration of 2 minutes needed to empty a container and assumes an occupancy rate of 1.4 persons per vehicle (following European Environment Agency of the European Union [2010].

$$P = (L_{passengercar} + L_{truck}) * 1.4 * (2/60) \tag{4.13}$$

where L is the number of vehicles per hour.

For congestion, no difference is made in elaboration steps for the affected population factor.

4.5 SPATIAL AGGREGATION

Impact values are calculated at vectors points, describing individual containers or house centroids, or vector lines, describing road segments. The values calculated at these entities could be spatially aggregated into areas, in order reduce the number of values which could be beneficial for interpretation of outcomes on large scale or for subsequent calculations. The following levels of spatial aggregation are tested:

1. No spatial aggregation at all (over 100.000 spatial entities in Amsterdam)
2. Aggregation to neighbourhoods (455 spatial entities in Amsterdam)
3. Aggregation to city parts (7 spatial entities)
4. Aggregation to city (1 spatial entity: i.e.no spatial variance and therefore defined as the *Non-Spatial* Impact value)

Both total values and average values are tested for spatial aggregation.

4.6 VALUE AGGREGATION

In order to aggregate values into one value, three steps are taken: normalisation, weighting and aggregation.

4.6.1 Normalisation

NORMALISATION OF INTENSITY VALUES Normalisation is done linearly between a lower and upper threshold value. For the relevant thresholds, explanation is given in the next paragraphs. After normalisation, the meaningful scale of the factor values has been lost, which changes the way in which values can be interpreted.

For noise intensity at the receptor, normalisation is done between the noise nuisance threshold of 70 dB [Mediapower Pro, 2018] and the default source emitted value of 100 dB.

For odour intensity at the receptor, similar principles are used. Based on work by Nicell [2009] (in his table 1), the odour nuisance threshold was set to 0.5 OU_E/s. According to Nicell [2009], this threshold corresponds with Dutch limits and guidelines. The upper threshold is set to the default source value of 236 OU_E/s, based on assuming a volume of 4 m^3 and a waste odour emission rate of 59 OU_E/s [Sironi et al., 2005].

For congestion at both source and receptor, values are calculated by division of the total load of a segment by its capacity, resulting in congestion rate values. It was chosen to mark a segment as congested when its congestion rate is 0.8 or higher.

For CO_2 Emission, only calculated at the source as explained in section 4.2, choosing a normalisation threshold is hard due to its lack of spatial variance. Eventually, the value of 3 kg/km was used. This choice was made based on the output values of the method itself.

For the upper waste collection threshold at the source, the capacity per container is used. By assuming each container to have a volume of 4 m^3 and organic waste to have a density of 400 kg/m^3 [Stichting Stimular, 2013], each container can collect up to 1600 kg per collection interval. At the receptor side, the upper threshold value is the mass collected by a household double the size of an average household. This is calculated by dividing the mass per inhabitant per year of 92 kg by the number of two weekly period 26 (52 weeks / 2), and multiplying that value with the average number of inhabitants per house in the current dataset. The same principle is used for normalisation of the affected population factor values.

Table 4.4 provides an overview of all intensity normalisation methods.

Table 4.4: Normalisation thresholds for intensity factor

Impact Indicator	Point of View	Normalisation method
Noise	Source	Boolean
	Receptor	linear with lower threshold 70dB (0) and upper threshold 100dB (1)
Odour	Source	Boolean
	Receptor	linear with lower threshold 0.5 OU_E/s (0) and upper threshold 236 OU_E/s (1)
Congestion	both	linear with lower threshold 0 (0) and upper threshold 0.8 (1)
CO_2 Emission	Source	linear with lower threshold 0 kg/km (0) and upper threshold 3 kg/km (1)
Waste Collection	Source	linear with lower threshold 0 kg (0) and upper threshold 1600 kg (1)
	Receptor	linear with lower threshold 0 kg (0) and upper threshold $2P_{average} * \frac{92}{26}$ kg (1)

NORMALISATION OF TEMPORALITY VALUES As explained in section 4.3, normalisation is inherent to the way in which the temporality factor is quantified: the temporal curves define a weight value on the y-axis between 0 and 1 for all possible time values on the x-axis.

NORMALISATION OF AFFECTED POPULATION VALUES For the affected population values, normalisation is done linearly between thresholds, where the lower threshold corresponds with 0 people. The upper threshold corresponds with twice the average number of people. The upper threshold is related to the average to make the threshold coherent for both source and receptor perspective. In addition, it is constant with the context data (i.e.houses and roads) and does not vary with the scenarios, therefore allowing for comparison of scenarios within the same area of context data. The average is multiplied with 2 in order to allow for sufficient variation in normalised values.

For noise and odour, receptors are houses. The average number of people is found by calculating the average number of people in the houses dataset currently used for the model. This value might therefore differ from dataset to dataset. For this case the value is often found to be around 7 people per house, when multiplied with 2 leading to an upper normalisation value of 14 people.

For noise and odour sources, containers, the same principle is used. The people density of the dataset is used: the average number of people per km^2 within the area of the dataset. This is calculated by generating a concave hull around the houses,

calculating the total amount of people within it and dividing this value by the total area of the concave hull. This people density value is multiplied with 2 to allow for sufficient variation. Then, the radius of the circle within which a source has impact is calculated followed by its area. The upper affected population threshold for the source is then the average number of people per km^2 * area in km^2 * 2.

Also for congestion, the upper threshold is defined as twice the average number of people. For both source and receptor, this value is calculated by finding the average total load for all segments in the dataset used. The total load is multiplied with the default occupancy rate of vehicles in order to find the number of people at the segment per hour. Then, the load is multiplied with the duration in hours to find the number of people within the period of impact (i.e.impact duration). In the end the value is multiplied with 2 again.

Table 4.5 provides an overview of all affected population factor normalisation methods.

Table 4.5: Normalisation thresholds for affected population factor

Impact Indicator	Point of View	Normalisation method
Noise	Source	linear with lower threshold 0 (0) and upper threshold $2\rho_{average} * A$ (1)
	Receptor	linear with lower threshold 0 (0) and upper threshold $2_{average}$ (1)
Odour	Source	linear with lower threshold 0 (0) and upper threshold $2\rho_{average} * A$ (1)
	Receptor	linear with lower threshold 0 (0) and upper threshold $2P_{average}$ (1)
Congestion	both	linear with lower threshold 0 (0) and upper threshold $2P_{average}$ (1)

4.6.2 Weighting

As already mentioned in the design choices, the choice was made to assign all factors the same weight: the intensity factor, temporality factor and affected population factor are all assigned weight 1.

4.6.3 Aggregation

THREE AGGREGATION METHODS In Chapter 2, multiple methods and principles to aggregate indicator scores were described. For factor aggregation in this research, the main demand to the aggregation method is that the method should yield a value of 0 in case one of the three factor values is 0, i.e.in case the intensity of the phenomenon below a defined impact threshold, in case the temporality is 0 (for example if the duration or frequency is 0) or in case there are no people affected by the impact. This yields logical outcomes for the indicator values. This demand is highly related to the concept of *andness* [Yager, 1988] and the concept of full compensation [Miller et al., 2013]. Note that this is the case for factor aggregation. In case of indicator aggregation (i.e.aggregating noise, odour, congestion, co_2 and waste collection scores into one overall score of the scenario) different demands are likely to apply. However, indicator aggregation was not researched.

Of the aggregation methods described in Chapter 2, only the WP method fulfilled the requirement. In order to test more methods, Boolean multiplication was used to incorporate the concept of full *andness* in the simplest and therefore most transparent of the other aggregation methods described: each factor is converted to a Boolean value, where each value larger than 0 becomes 1 (True) and a value of 0 stays 0 (False). The three Boolean factor values are multiplied with each other, re-

sulting in a value of 1 (True, impact being present) only if all three factors are True (equation 4.14). The outcome of the Boolean multiplication is then multiplied with the result of the aggregation method.

$$I_i = \prod j = 1^n (x_{ij}! = 0), \quad i = 1, ..., m \tag{4.14}$$

Firstly, the WP aggregation equation can be used, as described by 2.4 [Miller et al., 2013] and elaborated on in Chapter 2. In essence, this method multiplies all factor values with each other. To make this method fit the purpose, no Boolean multiplication is needed.

Secondly, the combination of Boolean multiplication and SAW as described by 2.3 [Miller et al., 2013] and elaborated on in Chapter 2 is used.

The outcome of the Boolean multiplication is multiplied with the outcome of equation 2.3. In essence, this method takes the weighted average of all factors values. Outcome of this second approach is an average value in case all factor values are higher than 0.

Thirdly, Boolean multiplication can be combined with the maximum value. The outcome of the aggregation is the Boolean value multiplied with the maximum of the three factor values. In essence, this method gives the maximum factor value as an impact value, after checking whether all are indeed larger than 0. This method is the only method which does not calculate a new value based on three existing values, but takes one of the existing values. It is therefore the only method which acknowledges that the three factors are described in different scales. However, it ignores the effect of two of the three factor values.

5 IMPLEMENTATION AND EXPERIMENTS

This chapter describes how the components of the spatio-temporal impact assessment method described in Chapter 4 were tested and implemented on the data and using the tools as defined in Chapter 3. The chapter starts with sections on data preparation followed by a section on generation of spatial planning scenarios from the data. Subsequently, all relevant tests of the designed method as well as their outcomes are elaborated on. In addition, the chapter describes the final implementation of the method components and their outcomes, which are appended in appendix E.

5.1 DATA PREPARATION

Processing of data is needed to make them usable for testing and implementation later on. Table 5.1 gives an overview of the general processing steps needed per dataset. In Appendix B section B.1 a detailed description is included.

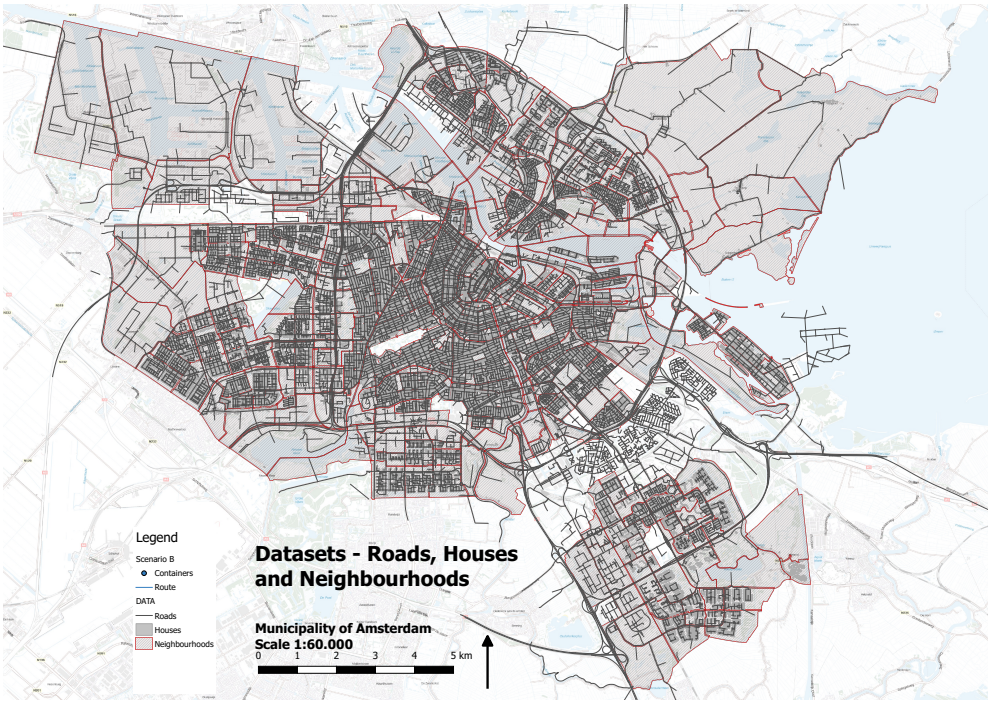
Table 5.1: Data processing general overview

Input dataset	Processing steps	Output dataset
BAG Residences [vector points]	Clip to municipality; remove residences without living function or which are not currently in use	Residences for living currently in use
CBS Neighbourhoods [vector polygons]	Clip to municipality; remove unncessary attributes; remove neighbourhoods without inhabitants; count BAG Residences per neighbourhood	Inhabited neighbourhoods with inhabitants and residence count
BAG Buildings [vector polygons]	Clip to municipality; remove small and unused buildings; clean overlaps and duplicates; count BAG Residences per building; join spatially with neighbourhoods; spread inhabitants over houses based on residences	Houses with inhabitants
VMA [vector lines]	Calculate traffic intensity and congestion per segment	Road segments with speed, load, capacity and congestion level

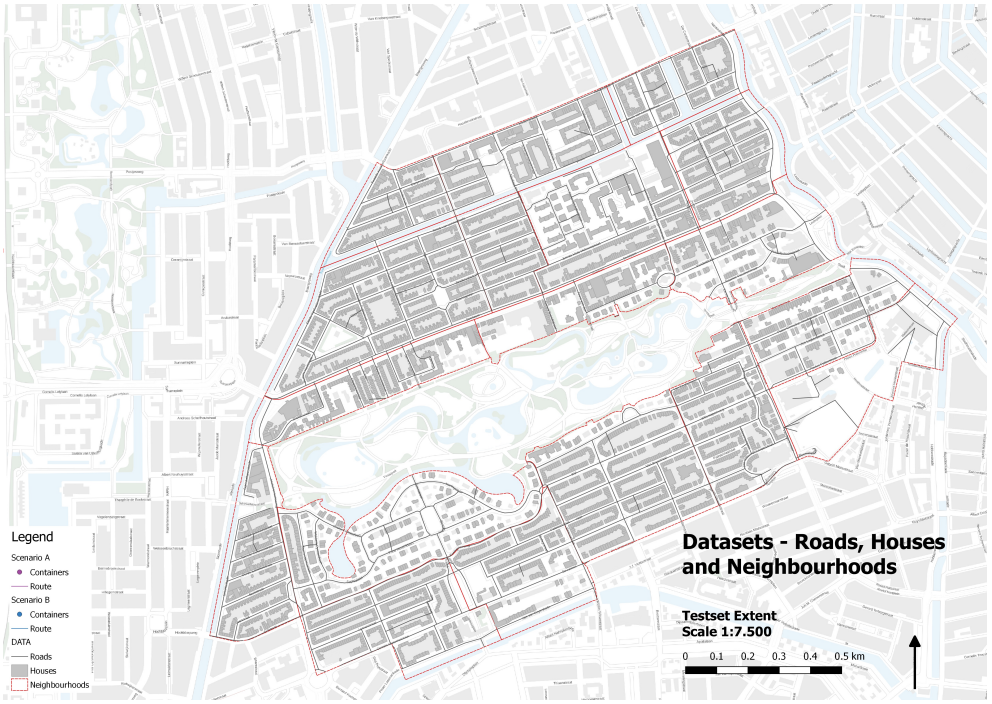
Figure 5.1 shows a visualisation of the processed houses, roads and neighbourhoods datasets for the whole city and for the test set area. Full size figures of all datasets are included in Appendix B in section B.2.

Figure 5.1: Visualisation of processed datasets Houses, Roads and Neighbourhoods

(a) Municipality of Amsterdam



(b) Test set area



5.2 DEFINITION AND GENERATION OF SCENARIOS

SCENARIO ASSUMPTIONS AND CHOICES The dummy scenarios were composed from data by Municipality of Amsterdam [2017] on the location of existing waste collection containers in Amsterdam. The assumption was made that the *decentralized* containers would be next to all existing paper containers, while the *centralized* containers would be next to all existing plastic containers. The fastest route along these containers was approximated using the road network dataset (VMA).

The timetable as shown in table 5.2 was assumed for the temporalities of the scenarios. In addition, it was assumed that the time to empty a waste container was 2 minutes (i.e.the duration of each container). However, for practical reasons this duration of emptying containers was not taken into account when calculating the moments in time of the subsequent road segments.

Table 5.2: Collection schedule per scenario

Scenario	Frequency	Starting time
Scenario A	Every two weeks: 1/14	10:00 AM
Scenario B	Twice a week: 4/14	06:00 AM

GENERATION OF SCENARIOS The first spatial version of the scenarios was composed manually. However, in order to extend the scenarios with temporalities the spatial scenarios had to be regenerated. This time, the process was automated in PyQGIS scripts: one for the spatial scenarios and a second subsequent script for the temporalities of the scenarios. In the scripts, the same spatial principles were used as in manual generation, but the spatial process was refined a bit further.

Table 5.3 provides a general overview of the input data, steps and output scenarios of the automated scenario generation process (i.e.the process used for the final scenarios).

Table 5.3: Scenario generation general overview

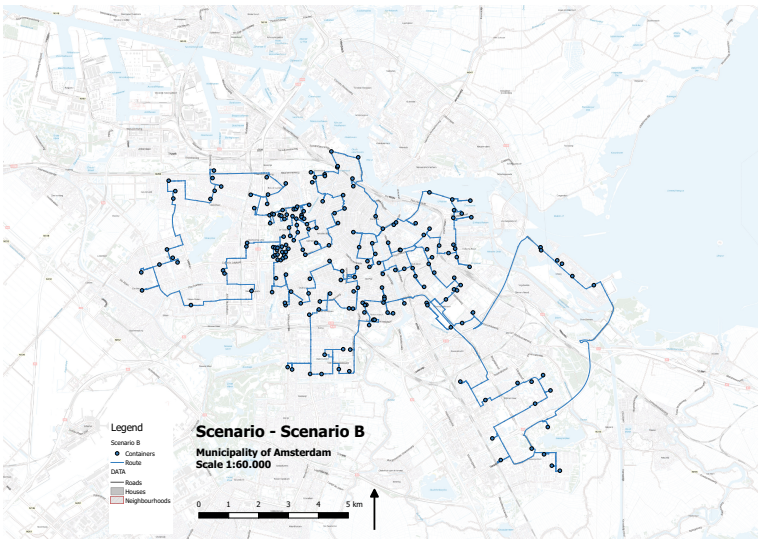
Input datasets	Processing steps	Output scenario
Containers [vector points]; VMA; schedule variables starting time, container duration and frequency	calculate length and travel time per segment; apply salesman algorithm to approximate fastest route along containers; join containers and sequence table of containers; join route and road network by location; sort containers and route segments on sequence; assign moment, duration and frequency to route segments; assign duration and frequency to containers; assign moment to containers based on route segment in proximity	Containers with sequence value, moment, duration and frequency; route along them with sequence value, moment, duration and frequency

Appendix C, section C.1, describes the generation of scenarios in detail. Both the manual and the automated generation steps are elaborated on. The PyQGIS scripts described in pseudo code in Appendix C are included in Appendix D as well.

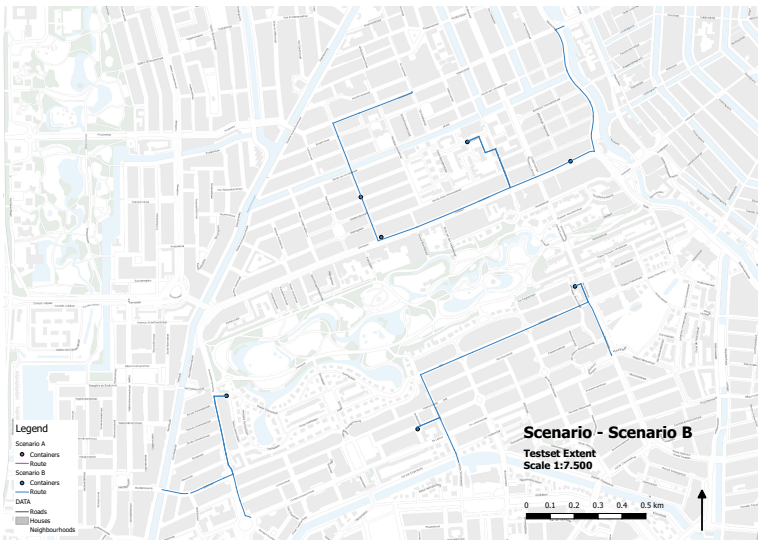
Figure 5.3 shows visualisations of Scenario B for both the whole city and the test set area and of Scenario A for the test set area only. Full size figures of the generated scenarios are included in Appendix C in section C.2.

Figure 5.3: Visualisation of Scenarios

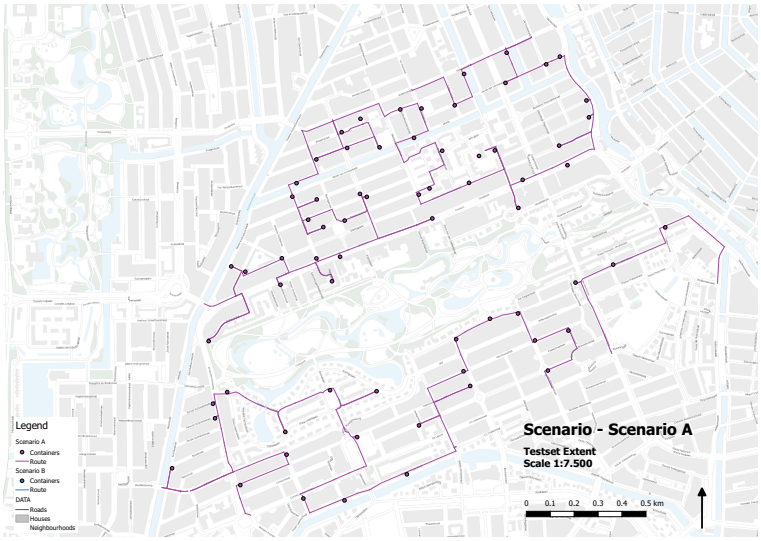
(a) Scenario B for Municipality of Amsterdam



(b) Scenario B for test set area



(c) Scenario A for test set area



5.3 SPATIO-TEMPORAL FACTOR MODELLING

5.3.1 Houses as Centroids

The indicators noise, odour and waste collection have houses as receptors. For calculation purposes, not the house polygons but the house centroids were used. However, this might distort impact models, since the receptor points are assumed further from the source points than the actual receptor polygons (i.e.houses) are. To correct this difference, an educated guess was made to extend the range of intensity for noise, odour and waste collection was extended with 10 meters.

For example, with the chosen default values for waste collection, the maximum distance from a house (i.e.receptor) to a container (i.e.source) in order for it to be accessible was calculated to be 141 meters. For implementation purposes, not the house polygons were used but their centroids, while the maximum distance was extended with 10 meters to a value of 151.

5.3.2 Noise Intensity and Affected Population Tests

SOURCES For noise receptors, the noise level was calculated for each house centroid, based on euclidean distance between the receptor and the nearest source. The QGIS tool Distance To Nearest Hub was used to achieve this. Circular areas of noise levels can be seen around each source in figure 5.6a. To calculate the affected population factor for the noise receptors (i.e.house centroids), the number of inhabitants of the house is taken. This number has been calculated in the data preparation.

RECEPTORS For noise sources, only Boolean intensity was calculated. The population affected by each source was taken into account from the first tests onwards. To do this, a buffer area around each container was generated with a radius defined by the source noise level and the noise nuisance threshold. The number of people within each buffer area was counted using the Count Points in Polygon Weighted tool in QGIS, and then the buffer polygons with people information were joined back to the container points. A visualisation is added in figure 5.6b.

Figure 5.5: Spatial noise modelling tests

(a) First test for spatial noise modelling from receptor: intensity level, not taking affected population into account

(b) First test for spatial noise modelling from source: Boolean intensity and affected population

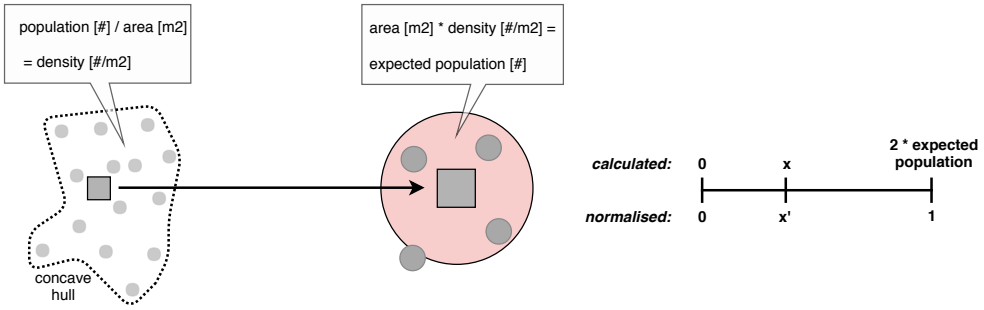
NORMALISATION OF AFFECTED POPULATION FACTOR For this research, the choice was made to normalise the affected population between 0 and twice the corresponding average number of people found in the data, as elaborated on in Chapter 4. This way to normalise results in loss of some information and might be intransparent in use for decision makers.

However, this choice was made since it is deemed most meaningful: if thresholds were to be chosen, many assumptions would have to be made especially in case

of normalisation for a source (for example population affected by a container) and therefore lose meaning. A chosen threshold would also ignore differences in population density of cities and would therefore be very region specific. In addition, the chosen normalisation allows for comparison of different scenarios: normalisation between best and worse for example would not allow so. Finally, it allows for comparison of the outcomes of receptor based and source based calculation, since it yields upper thresholds which are coherent for both source and receptor approach, which is of value for the research process.

For each source, the normalised affected population factor is calculated by generating a QGIS Concave Hull around all possible receptors in the dataset, applying QGIS Join By Location to the receptors and the concave hull and thereby finding the sum of all people within the concave hull. This sum is divided by the area, resulting in a people density value: the number of people per square kilometre. In case the hull consists of multiple features, all are taken into account in calculating the average using a loop over the features. Afterwards, the area of noise impact around each container is calculated by multiplying the squared noise radius r^2 (i.e.the distance over which the noise source value cause nuisance, for example the distance needed for 100 dB to diminish to 70 dB) with 2π. For every source, the population it affects is linearly normalised between 0 and 2 * the calculated average value. A conceptual overview of these steps is visualised in figure 5.7. For each source, its normalised intensity factor is equal to its Boolean intensity value (i.e.it is already either 0 or 1).

Figure 5.7: Conceptual overview of steps for normalisation of affected population factor



For each receptor, the intensity level is linearly normalised between the lower and upper noise threshold level. In order to be able to normalise the affected population factor of a receptor, the average number of people of all houses is calculated. This is done by looping over all houses in the layer, summing their inhabitants and dividing it by the total number. The average number of people is doubled and normalisation is performed linearly between 0 people and the average times 2. It was found that for the test set, the average number of people per house lies around 7. However, this average might differ dependent on the data.

By linking the affected population factor normalisation to the dataset, instead of choosing fixed values, the source and receptor normalisation are consistent. In addition, it allows for scaling the method to areas which are less or more densely populated.

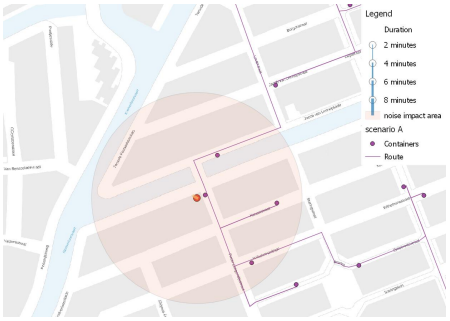
5.3.3 Noise and Odour Temporality Tests

RECEPTOR For the impact at the noise and odour receptor, the moment in time and frequency of the impact are inherited from the impact source which is closest in Euclidean distance. This source, closest in Euclidean distance, also defines the intensity of the impact. This is done using the QGIS tool Distance to Nearest Hub, also incorporating the name or id of the nearest hub, followed by Join Attributes by Table to join the temporalities of the nearest source to the receptor.

For the duration of the impact at the noise and odour receptor, a calculation is made on how many impact sources are within reach of the impact (i.e.for noise using the default parameters within roughly 150 metres). This is done by generating a QGIS Buffer polygon around each receptor and usage of the QGIS tool Count Points in Polygon. Then the receptor and its buffer are joined back into one based on id. The duration at the receptor is then the number of sources in proximity times the default duration of emptying a container in the scenario. Figure 5.8 shows the principle for 2 receptors: sub figure 5.9a shows a house which is within 150 meter proximity of 2 containers, while sub figure 5.9b shows a house in proximity of 4.

Figure 5.8: Duration at receptor affected by the number of containers within range of the impact: experiment for noise with impact range of 150m

(a) 2 containers: 4 minutes



(b) 4 containers: 8 minutes

Note that this duration principle can only work when assuming the duration of emptying containers to be constant within the scenario, which is the case for the current implementation. This method also assumes the emptying of containers in spatial proximity to be close in time as well. However, this is not necessarily the case and therefore might cause a bias for specific cases. A way to deal with this bias could be to check whether the impacts received from different sources are indeed close in time. If they are not, for example when two impacts are more than an hour apart and therefore not experienced as one impact, the second impact could be treated by extending the frequency with one other occurrence, instead of extending the duration. However, this principle was not tested.

SOURCE The impact temporalities of the noise and odour source, both containers, are inherited from the scenario: the temporalities of the emptying of the container. This accounts for all three temporalities.

5.3.4 Noise Final Implementation

The final implementation of noise impact calculation from receptor side is given in pseudo code in Algorithm 5.1. Similar pseudo code is given for the source point of view in Algorithm 5.2. The relevant variables values and layers needed as inputs are given in the algorithm as well. The full PyQGIS scripts are included in Appendix D and its outputs maps in Appendix E Section E.1.

5.3.5 Odour Intensity and Affected Population Tests

For odour, the tests performed are highly similar to those for noise. However, it is clear that odour intensity spreads over a rather small area compared to noise. Therefore, the population affected by the container is smaller as well. The way in which calculation and normalisation of intensity and affected population factors are performed is similar to the calculation for noise.

Algorithm 5.1: NoiseAtReceptor (*containers*, *houses*)

Input: layer *containers* (points; attributes *moment*, *duration*, $frequency$), layer *houses* (polygons; attribute *people*), E = 100 dB, L = 70 dB, c = 3 dB, *rho* = 0.02

Output: layer *houses_noise_impact* (points; attributes *intensity*, *moment*, *duration*, $frequency$, *people*, $F_{intensity}$, $F_{temporality}$, $F_{population}$, $impact$)

1 $D_{building}$ = 10.0 * (E - L) * ρ * c;
2 $r = 10.0^{(E-L-D_{building})/10.0}$;
3 QGIS Field Calculator: *containers joincat* = *textrm@rownumber*;
4 QGIS Distance To Nearest Hub: d = distance *houses* to *containers* //temporalities of closest container assigned to house;
5 QGIS Join Attributes By Table: *houses* (*joincat*) with *nearesthub* (*hubname*);
6 QGIS Count Points in Polygon: *containers* in houses buffer zone with radius r;
7 **for** *house in houses* **do**
8 $intensity = E - 10.0 * \log d - D_{building}$;
9 $F_{intensity}$ = normalise($intensity$) between L and E;
10 F_{moment} = temporalweightcurve(*moment*);
11 $F_{duration}$ = temporalweightcurve(*duration*);
12 $F_{frequency}$ = temporalweightcurve($frequency$);
13 $F_{temporality}$ = aggregate(F_{moment}, $F_{duration}$, $F_{frequency}$);
14 $F_{population}$ = normalise(*people*) between 0 and $2 * average_{houses}(people)$;
15 $impact$ = aggregate($F_{intensity}$, $F_{temporality}$, $F_{population}$);

Algorithm 5.2: NoiseFromSource (*containers*, *houses*)

Input: layer *containers* (points; attributes *moment*, *duration*, $frequency$), layer *houses* (polygons; attribute *people*), E = 100 dB, L = 70 dB, c = 3 dB, *rho* = 0.02

Output: layer *containers_noise_impact* (points; attributes *intensity*, *moment*, *duration*, $frequency$, *people*, $F_{intensity}$, $F_{temporality}$, $F_{population}$, $impact$)

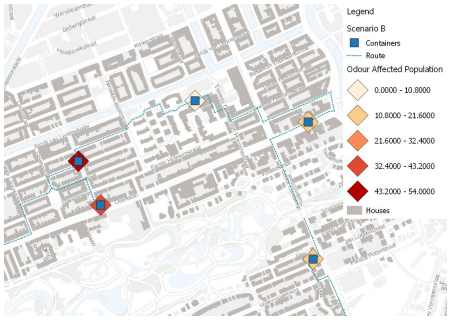
1 $D_{building}$ = 10.0 * (E - L) * ρ * c;
2 $r = 10.0^{(E-L-D_{building})/10.0}$;
3 QGIS Buffer: *containers* with radius r;
4 QGIS Count Points in Polygon Weighted: *people* affected by *container*;
5 QGIS Concave Hull and Count Points in Polygon Weighted: *allpeople* in total hull *area* of *houses*;
6 thr_{people} = *allpeople / area* * 2.0 * π * r^2;
7 **for** *container in containers* **do**
8 $intensity = F_{intensity} = 1$;
9 F_{moment} = temporalweightcurve(*moment*);
10 $F_{duration}$ = temporalweightcurve(*duration*);
11 $F_{frequency}$ = temporalweightcurve($frequency$);
12 $F_{temporality}$ = aggregate(F_{moment}, $F_{duration}$, $F_{frequency}$);
13 $F_{population}$ = normalise(*people*) between 0 and thr_{people};
14 $impact$ = aggregate($F_{intensity}$, $F_{temporality}$, $F_{population}$);

SMALL SPREAD Since the area over which odour spreads is smaller than the area over which noise spreads, an interesting difference can be seen in the pattern of affected population by the containers. An example is the top middle container in figures 5.6b and 5.11b. The direct area around this container contains almost no houses, resulting in very few people affected by the container in terms of odour (figure 5.11b). However, the wider area around the container is populated, meaning that the container does have an impact in terms of noise (figure 5.6b). The receptor noise and odour levels in figures 5.6a and 5.11a confirm this effect.

Figure 5.10: Spatial odour modelling tests

(a) First test for spatial odour modelling from receptor: intensity level, not taking affected population into account

(b) First test for spatial odour modelling from source: Boolean intensity and affected population



5.3.6 Odour Final Implementation

The final implementation of odour impact calculation from receptor side is given in pseudo code in Algorithm 5.3. Similar pseudo code is given for the source point of view in Algorithm 5.4. The relevant variables values and layers needed as inputs are given in the algorithm as well. The full PyQGIS scripts are included in Appendix D and its outputs maps in Appendix E Section E.2.

5.3.7 Congestion Intensity and Affected Population Tests

For the congestion intensity tests, a container was assigned the maximum congestion level (either morning rush hour, day or evening rush hour dependent on the segment) of the road segments within proximity. This is done by generating a QGIS Fixed Distance Buffer around the container and applying QGIS Join Attributes By Location to the buffer and the road segments, taking the maximum values of all joined features to the buffer. The buffer is then joined back to the container by table. The test can be seen in figure 5.12. This test does not take into account the affected population, and neither does it take into account the temporality: when temporality is taken into account later on, it is found that the container which seems to have a congestion impact based on its intensity, is not visited during rush hours and therefore does not have a congestion impact.

For each congestion receptor (i.e.road segment), the number of people is calculated by summing its truck and car load and multiplying the value with the default duration in hours and the default vehicle occupancy (i.e.the number of people per vehicle). For each congestion source (i.e.container), the same principle is used but taking the maximum loads from the roads segments within proximity.

NORMALISATION OF AFFECTED POPULATION FACTOR Normalisation of the affected population factor for congestion is done based on the average number of people travelling on all roads, for both source and receptor point of view. This is

Algorithm 5.3: OdourAtReceptor (*containers*, *houses*)

Input: layer *containers* (points; attributes *moment*, *duration*, *frequency*), layer *houses* (polygons; attribute *people*), C = 59 $OU_E/s/m^2$, A = 4 m^2, C_{thres} = 0.5 OU_E/s, V = 48.2 m/s

Output: layer *houses_odour_impact* (points; attributes *intensity*, *moment*, *duration*, *frequency*, *people*, $F_{intensity}$, $F_{temporality}$, $F_{population}$, *impact*)

$r = (C * A/(C_{thres} * \pi * U * 0.04422))^{0.64255}$;

QGIS Field Calculator: *containers joincat = textrm@rownumber*;

QGIS Distance To Nearest Hub: d = distance *houses* to *containers* //temporalities of closest container assigned to house;

QGIS Join Attributes By Table: *houses* (*joincat*) with *nearesthub* (*hubname*);

QGIS Count Points in Polygon: *containers* in houses buffer zone with radius r;

for *house in houses* **do**

  $intensity = C * A/(\pi * 0.04422 * d^{1}.5563 * U)$;

  $F_{intensity}$ = normalise($intensity$) between C_{thres} and C;

  F_{moment} = temporalweightcurve(*moment*);

  $F_{duration}$ = temporalweightcurve(*duration*);

  $F_{frequency}$ = temporalweightcurve(*frequency*);

  $F_{temporality}$ = aggregate(F_{moment}, $F_{duration}$, $F_{frequency}$);

  $F_{population}$ = normalise(*people*) between 0 and $2 * average_{houses}(people)$;

  impact = aggregate($F_{intensity}$, $F_{temporality}$, $F_{population}$);

Algorithm 5.4: OdourFromSource (*containers*, *houses*)

Input: layer *containers* (points; attributes *moment*, *duration*, *frequency*), layer *houses* (polygons; attribute *people*), E = 100 dB, L = 70 dB, c = 3 dB, *rho* = 0.02

Output: layer *containers_odour_impact* (points; attributes *intensity*, *moment*, *duration*, *frequency*, *people*, $F_{intensity}$, $F_{temporality}$, $F_{population}$, *impact*)

$r = (C * A/(C_{thres} * \pi * U * 0.04422))^{0.64255}$;

QGIS Buffer: *containers* with radius r;

QGIS Count Points in Polygon Weighted: *people* affected by *container*;

QGIS Concave Hull and Count Points in Polygon Weighted: *allpeople* in total hull *area* of *houses*;

thr_{people} = *allpeople / area* * 2.0 * π * r^2;

for *container in containers* **do**

  $intensity = F_{intensity} = 1$;

  F_{moment} = temporalweightcurve(*moment*);

  $F_{duration}$ = temporalweightcurve(*duration*);

  $F_{frequency}$ = temporalweightcurve(*frequency*);

  $F_{temporality}$ = aggregate(F_{moment}, $F_{duration}$, $F_{frequency}$);

  $F_{population}$ = normalise(*people*) between 0 and thr_{people};

  impact = aggregate($F_{intensity}$, $F_{temporality}$, $F_{population}$);

done for the morning rush hours, evening rush hours and rest of day, using the corresponding loads. The average load is calculated by looping over all roads, determining their direction (either from A to B or from B to A) and summing the truck load and car load for the right direction. The sum of all relevant loads is divided by the number of features for which the load is known to arrive at an average load. This load is multiplied with 2 to find the value corresponding to twice the average load, which will be used for normalisation as explained in Chapter 4. Subsequently, the twice average load is multiplied with the default duration in hours and the default vehicle occupancy to find the number of affected people within the duration and corresponding to twice the average.

Figure 5.12: Spatial congestion modelling tests: level of intensity, not taking affected population and temporality into account

5.3.8 Congestion Temporality Tests

RECEPTOR For congestion, temporalities not only define the temporal factor but also the spatial intensity factor: the moment in time defines which loads and capacities are used to calculate the congestion intensity and affected population factor (i.e.morning rush hour, evening rush hour or general hours). In addition the duration defines how far in space the congestion can possibly extend.

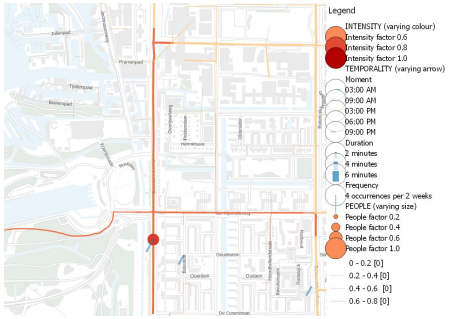
The moment of the receptor, the most congested road segment within a 10 metre Euclidean distance from a source, is directly inherited from this source. This also accounts for the duration and frequency values.

In case the intensity of the receptor segment is half the threshold value or higher (i.e.using default value of 0.4 or more), the congestion spatially spreads over the network. The extent of this spread is dependent on the duration of the congestion impact at the receptor. This duration is combined with speed to find spreading distance. Since the duration is constant within the scenarios and therefore constant for all congestion receptors as well, the spreading distance does not vary. QGIS tools Extract By Attribute, Polygon Centroids and GRASS GIS tool v.net.iso are used to implement the principle. Figure 5.13 shows the effect of the duration in terms of spatial spread of the receptor impact.

Figure 5.13: Spatial spread of receptor congestion impact over the network caused by the duration of the impact and speed of vehicles

(a) No spatial spread

(b) Spatial spread with duration



Note that the spread of congestion is defined as where congestion could spread to instead of where it is likely to spread to: for example at crossroads or at way roads, congestion is likely to spread differently than estimated by this model, where congestion spreads equally to all directions.

For practical reasons, the road segments representing the spread of congestion impact at the receptor side are not assigned their own temporalities. However, visualisation of the intensity, affected population and temporalities of the receptor segment itself combined with visualisation of only the intensity and affected population factor on the spreading segments is deemed sufficient information for the user.

SOURCE Similarly to the source temporalities of noise and odour, the congestion impact temporalities of a source are directly inherited from the scenario: the moment, duration and frequency with which the container is emptied apply for the impact it causes as well.

5.3.9 Congestion Final Implementation

The final implementation of congestion impact calculation from receptor side is given in pseudo code in Algorithm 5.5. Similar pseudo code is given for the source point of view in Algorithm 5.6. The relevant variables values and layers needed as inputs are given in the algorithm as well. The full PyQGIS scripts are included in Appendix D and its outputs maps in Appendix E Section E.3.

5.3.10 CO_2 Emission Tests

The first CO_2 Emission tests were performed based on the length of the segments only. When visualisation is done per segment, it only varies with difference in length and therefore does not provide any additional spatial variant information. If normalisation to length is performed, all segments have equal values as long as speed and vehicle load differences are ignored.

Therefore, the choice was made to visualise this experiment in grid cells: grid cells are coloured according to distance of the route within the cell, as can be seen in figure 5.15. In case the route follows the same route to and from a container, both distances add up in terms of CO_2 Emission. This can be seen in the darker orange cells at the left.

From these tests, it was concluded that CO_2 Emission should be measured based on spatial data, but is not necessarily interesting to visualise and interpret spatially. However, influence of vehicle speed and load might enlarge the spatial variance of CO_2 Emission and should therefore be included in the final implementation.

Algorithm 5.5: CONGESTIONATRECEPTOR (*containers*, *roads*)

Input: layer *containers* (points; attributes *moment*, *duration*, $frequency$), layer *roads* (lines; attributes *speed*, $load_{car}$, $load_{truck}$, $capacity$ for morning rush hours, evening rush hour and general hours), r = 10.0 m, $occupancy$ = 1.4 people, C_{thres} = 0.8

Output: layer *road_congestion_impact* (points; attributes *intensity*, *moment*, *duration*, $frequency$, *people*, $F_{intensity}$, $F_{temporality}$, $F_{population}$, $impact$)

1 QGIS Buffer: *containers* with radius r;
2 QGIS Clip and Join Attributes By Location: *roads* in buffer with *container* temporalities;
3 thr_{people} calculated for morning rush, evening rush and general hours = 2.0 * average *load* in *roads* * $occupancy$ * (*duration* / 60.0);
4 **for** *segment in roads* **do**
5 //use variables from morning rush, evening rush or general hours dependent on *moment*;
6 $intensity = load_{car} + 2.0 * load_{truck}/capacity$;
7 $F_{intensity}$ = normalise($intensity$) between 0 and C_{thres};
8 F_{moment} = temporalweightcurve(*moment*);
9 $F_{duration}$ = temporalweightcurve(*duration*);
10 $F_{frequency}$ = temporalweightcurve($frequency$);
11 $F_{temporality}$ = aggregate(F_{moment}, $F_{duration}$, $F_{frequency}$);
12 $people = load_car + 2.0 * load_{truck} * capacity$; $F_{population}$ = normalise($people$) between 0 and thr_{people};
13 $impact$ = aggregate($F_{intensity}$, $F_{temporality}$, $F_{population}$);
14 r_{spread} = *speed* * 1000.0/60.0 * *duration*;
15 QGIS Extract By Attribute: *roads* where $F_{intensity}$ ¿ C_{thres}/2.0;
16 GRASS GIS v.net.iso: affected *roads* segments in *isolines* within network distance r_{spread};
17 QGIS Join Attributes By Location: *isolines* with *roads*;
18 **for** *segment in roads* **do**
19 **if** *intensity* = *NULL* **then**
20 //use variables from morning rush, evening rush or general hours dependent on *moment*;
21 $intensity$ = 0.5 * C_{thres};
22 $F_{intensity}$ = normalise($intensity$) between 0 and C_{thres};
23 $people = load_car + 2.0 * load_{truck} * capacity$;
24 $F_{population}$ = normalise($people$) between 0 and thr_{people};

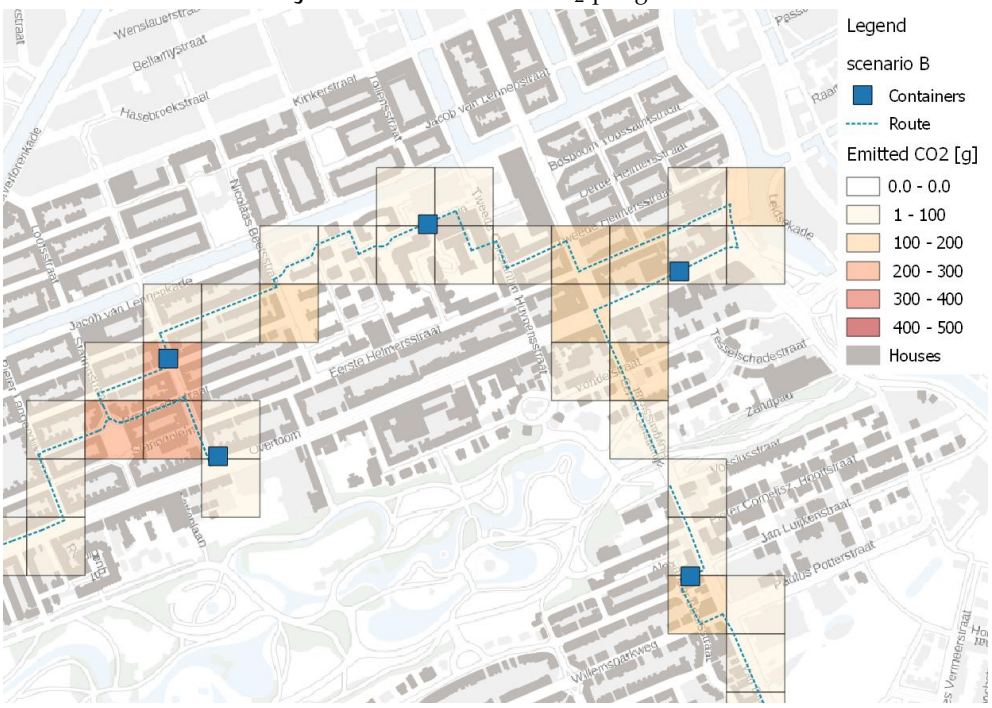
Algorithm 5.6: CONGESTIONFROMSOURCE (*containers*, *roads*)

Input: layer *containers* (points; attributes *moment*, *duration*, *frequency*), layer *roads* (lines; attributes *speed*, $load_{car}$, $load_{truck}$, *capacity* for morning rush hours, evening rush hour and general hours), r = 10.0 m, *occupancy* = 1.4 people, C_{thres} = 0.8

Output: layer *container_congestion_impact* (points; attributes *intensity*, *moment*, *duration*, *frequency*, *people*, $F_{intensity}$, $F_{temporality}$, $F_{population}$, *impact*)

1 QGIS Buffer: *containers* with radius r;
2 QGIS Join Attributes By Location: maximum attribute values of *roads* in buffer assigned to *containers*;
3 thr_{people} calculated for morning rush, evening rush and general hours = 2.0 * average *load* in *roads* * *occupancy* * (*duration* / 60.0);
4 **for** *container in containers* **do**
5 //use maximum variable values from morning rush, evening rush or general hours dependent on *moment*;
6 $intensity = load_{car} + 2.0 * load_{truck}/capacity$;
7 $F_{intensity}$ = normalise(*intensity*) between 0 and C_{thres};
8 F_{moment} = temporalweightcurve(*moment*);
9 $F_{duration}$ = temporalweightcurve(*duration*);
10 $F_{frequency}$ = temporalweightcurve(*frequency*);
11 $F_{temporality}$ = aggregate(F_{moment}, $F_{duration}$, $F_{frequency}$);
12 $people = load_car + 2.0 * load_{truck} * capacity$; $F_{population}$ = normalise(*people*) between 0 and thr_{people};
13 *impact* = aggregate($F_{intensity}$, $F_{temporality}$, $F_{population}$);

Figure 5.15: Emission of CO_2 per grid cell



5.3.11 CO_2 Final Implementation

The final implementation of CO_2 impact calculation is given in pseudo code in Algorithm 5.7. The relevant variables values and layers needed as inputs are given in the algorithm as well. The full PyQGIS script is included in Appendix D and its outputs maps in Appendix E Section E.4.

Algorithm 5.7: CO2FROMSOURCE (*route*, *roads*)

Input: layer *route* (lines; attribute *sequence*), layer *roads* (lines; attribute *speed*), M_{thres} = 3 kg

Output: layer *route_co2_impact* (lines; attributes *totalmass*, *intensity*, $F_{intensity}$, *impact*)

```
1 QGIS Field Calculator: route mylength = $length;
2 QGIS Join Attributes By Location: route with roads;
3 sequence_maximum = max(sequence);
4 for segment in route do
5     F_sequence = normalise(sequence) between 1 and sequence_maximum;
6     fuel_consumption = 100.0 * F_sequence * 0.001167 + 0.15797;
7     totalmass = mylength / 1000.0 * fuel_consumption * speedfactor(speed) *
        2.63 * frequency;
8     intensity = totalmass / (mylength / 1000.0) // mass normalised for
        length of segment;
9     F_intensity = impact = normalise(intensity) between 0 and M_thres;
```

5.3.12 Waste Collection Tests

Spatially, the main variable in waste collection calculation is accessibility: how well does a house have access to a container? How well is a container accessible to surrounding houses? Therefore, this sub section on waste collection tests will focus on accessibility calculation tests.

TOOLS AND DATA FOR ACCESSIBILITY CALCULATION AT RECEPTOR For waste collection, tests were performed using both euclidean distance and network distance between houses (i.e.receptors) and containers (i.e.sources). The euclidean distance was calculated by converting all house polygon to centroids and then using the QGIS tool Distance to Nearest Hub. However, use of euclidean distances might be inaccurate in the Amsterdam urban environment due to its housing blocks, canals and parks combined with using the rather short waste collection threshold distance (i.e.141 meter).

The network distance was calculated by converting all house polygons to centroids followed by the GRASS GIS tool v.net.distance. This tool approximates the shortest path over the network from each house centroid to the container closest over the same network.

The v.net.distance tool uses snapping to connect sources (i.e.containers) and receptors (i.e.houses) to the network. Snapping is done by connecting points directly perpendicular to a line segment in proximity (i.e.not to nodes or line centroids, but directly perpendicular to a line segment). Snapping might cause errors in the accessibility calculation and will therefore be discussed in some more detail when network calculation outcomes are described.

The v.net.distance tool gives only path segments as output, where all path segments have their corresponding whole path length as an attribute. Therefore a reconstruction is needed to know which path and therefore which network distance belongs to which house. This reconstruction is done by using the QGIS tool Join By

Location, which is set to join the distance attribute of the path segments to a receptor in proximity. To do so a precision threshold has to be identified, since the centroids and paths (i.e.network) do not intersect each other. Details on this precision threshold will be elaborated on when discussing the outcomes of the experiments. In case multiple paths are within joining proximity of a house, the minimum values (i.e.the shortest distance) is assigned to the house: is multiple routes pass by, the minimum defines the path which starts at that receptor while the paths with longer distances belong to paths passing by.

To allow fruitful network calculation experiments, the road network dataset (the VMA) was checked for its usability for accessibility calculations. The dataset is meant for motorised vehicles and does include data about the directions of road segments (i.e.one way streets and their direction). Roads or paths which are accessible by foot or bike but not by car are not included in the dataset. This might raise errors which cannot be solved other than by using another more complete road network dataset. However, such a dataset was not available within this research. The data about direction of road segments was ignored for the waste collection accessibility experiments, since people offering waste by foot and bike are assumed not to be restricted by these directions.

RECEPTOR ACCESSIBILITY TESTS As explained, tests were performed with euclidean distances (QGIS tool Distance to Nearest Hub) as well as network distances (GRASS GIS tool v.net.distance). Between the two calculations, a big difference was found. Figure 5.17a shows in dark green the houses which have access to containers assuming euclidean distance, while figure 5.17b shows that many houses which seem to have access in the euclidean computation, do not have access when using the network distance.

The visualisation of the network test in figure 5.17b also shows that not for all houses a network distance could be calculated. This is caused by use of the QGIS tool Join by Location: not to all houses a path distance could be joined. This test has used a precision threshold for joining of 20 meters. With this threshold, only 1837 (33%) houses out of the 5536 houses in the dataset could be joined to a path. Corresponding to the precision threshold of 20 meters, a snapping threshold of 20 meters was used.

Figure 5.16: Spatial waste collection modelling tests: accessibility at receptor

(a) Euclidean distance from house to container nearest in euclidean space

(b) Network distance from house to container nearest over the network

For each house to which both the euclidean and the network distance is known, the difference between the two was calculated. These differences are visualised in figure 5.18. It can clearly be seen that the houses North of the middle-Northern container seem to have access in euclidean distance, but when network distances are used the canal obstructs the paths such that their accessibility over the network largely differs from their euclidean accessibility.

In addition, it is interesting to see that in the background map a small bridge seems to be present over the canal, directly next to the bright pink houses for which the accessibility difference is largest (figure 5.18). This small bridge is seen in white in the background map but not in black in the roads dataset. This could be an example of an important road segment which is accessible to people by foot, but not by car and therefore illustrates the fact that the VMA dataset is not fully fit for the waste collection accessibility purpose.

Figure 5.18: Difference between Euclidean and Network distance calculation for houses to which both are known

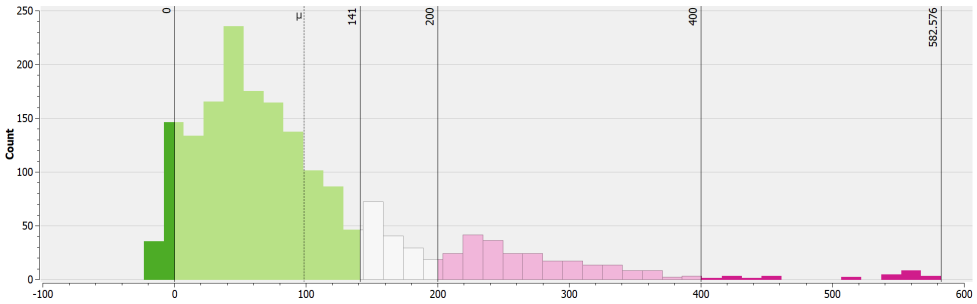
Figure 5.20a shows the histogram of calculated difference values corresponding to the map in figure 5.18. The histogram shows that the mean difference between euclidean and network distance for this test set lies around 100 meters, with a maximum of 583 meters. It is expected that this difference is mainly caused by the fact that euclidean distance calculations are inaccurate.

However, it should be noted that the influence of the snapping and precision thresholds of 20 meters remains, as well as the influence of the the fact that road segments not accessible by motorised vehicles are not present in the network dataset used. In case the experiment is repeated with a lower precision and snapping threshold of 10 meters, only for 67 houses (1%) their network distance is found, visualised in histogram in figure 5.20b. For those houses, a mean difference between euclidean and network distance of 115 meters is found, with a maximum of around 480 meters. By this comparison it seems that changing the threshold value affects the number of fruitful calculations rather than the accuracy: the pattern in the two histograms seems roughly the same. Note that the x-axes of both histograms in figure 5.19 slightly differ.

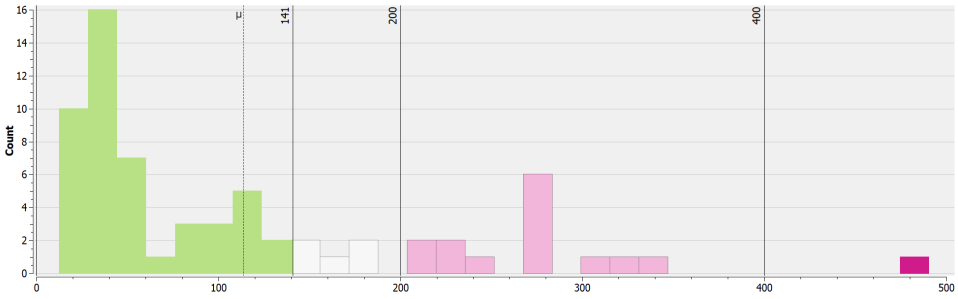
In the histogram in figure 5.20a, it can be found that some receptors have a calculated network distance which is shorter than the corresponding euclidean distance: up to a 22 meters difference. This effect seems to be caused by the snapping procedure: with snapping containers and houses to the network, the network distance between the two might seem too short (i.e.in case the segments the points are snapped to are closer to each other than the points are). In case the network path between them is rather straight as well, the network distance might be calculated

Figure 5.19: Histogram showing difference between euclidean distance and network distance calculation

(a) Difference with snapping distance threshold of 20 meters



(b) Difference with snapping distance threshold of 10 meters



shorter than the euclidean distance between the points. This effect can be seen in the map in figure 5.18.

TOOLS AND DATA FOR ACCESSIBILITY CALCULATION OF SOURCE For accessibility computation from a source point of view, the same difference between euclidean and network distance applies. To calculate the area to which a container is accessible in euclidean distance, a 141 meter buffer was drawn around each container.

To calculate the area to which a container is accessible over the network, GRASS GIS tool v.net.iso was used to find the extent of the network accessible within 141 meters. Afterwards a QGIS Concave Hull was created to transform the network segments to an area and then the QGIS Buffer tool was used in order to have the buffer overlapping all houses belonging to the network. A buffer radius of 10 meters is used. Similarly to noise and odour source calculations, intensity values of source are boolean only and therefore not spatially variant. The number of people each container is accessible to is calculated using QGIS tool Count Points in Polygon Weighted.

Also this network calculation is affected by the lack of road segments accessible for foot and bike but not for motorised vehicles in the dataset. In addition, small errors might be raised by drawing the buffer: erroneous inclusion or exclusion of houses. This effect is estimated to be similar to the effect of snapping in the receptor accessibility calculation.

SOURCE ACCESSIBILITY TESTS Figure 5.21 shows the outcomes of both accessibility calculations. It can be seen that the accessibility areas in the network calculation are for some cases far from round: the container at the right of the figure shows the biggest shape difference.

The shape of the concave hull, and therefore the extent to which the area matches the network, is determined by the threshold value set in the QGIS Concave Hull tool. This value can range from 0 to 1, where 1 equals a convex hull. Figure 5.23

Figure 5.21: Spatial waste collection modelling tests: accessibility area modelled from source

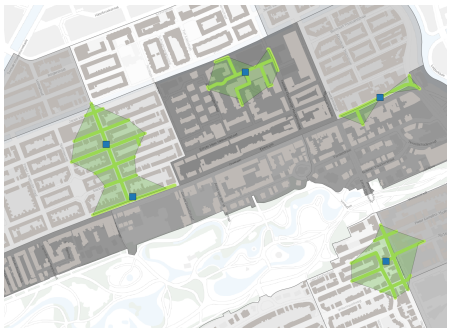
(a) Area to which container is accessible using euclidean distance

(b) Area to which container is accessible using network distance

Figure 5.23: QGIS tool Concave Hull applied to isolines as points: tests with threshold values from 0 to 1, where 1 is convex hull

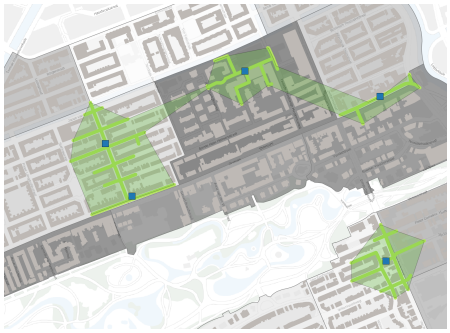
(a) Threshold value 0.01

(b) Threshold value 0.1



(c) Threshold value 0.2

(d) Threshold value 0.3



shows the influence of this value. From these experiments, it was concluded that a threshold value of 0.1 gives the most accurate outcome.

5.3.13 Waste Collection Final Implementation

The final implementation of waste collection impact calculation from receptor side is given in pseudo code in Algorithm 5.8. Similar pseudo code is given for the source point of view in Algorithm 5.9. Note that both algorithms model the waste collection impact indicator using euclidean distances. For the receptor algorithm (Algorithm 5.8), this is due to the fact that not all houses could be assigned a network distance. As mentioned earlier, this is caused by the Join Attributes by Location tool, which is not able to join a path to each house. For the source algorithm (Algorithm 5.9), this is due to implementation issues, as well as efficiency issues in case of assessing the whole city.

The relevant variables values and layers needed as inputs are given in the algorithm as well. The full PyQGIS scripts are included in Appendix D and its outputs maps in Appendix E Section E.5.

Algorithm 5.8: WasteCollectionAtReceptor (*containers*, *houses*)

Input: layer *containers* (points; attribute $frequency$), layer *houses* (polygons; attribute *people*), $frequency_{bringingwaste}$ = 2, $distance_{year}$ = 29100.0 m, *waste* = 92.0 kg, *rho* = 400 kg/m^3, *size* = 2 m^3, *willingness* = 0.3

Output: layer *houses_waste_impact* (points; attributes *totalmass*, *intensity*, $F_{intensity}$, *impact*)

d_{max} = $distance_{year}$ / (52.0 * 2.0 * $frequency_{bringingwaste}$);

QGIS Field Calculator: *containers joincat* = *textrm@rownumber*;

QGIS Distance To Nearest Hub: d = distance *houses* to *containers* //Euclidean distance used for current implementation;

M_{thres} = (*waste* / 26.0) * 2.0 * average(*people*);

for *house in houses* **do**

  A = (d_{max} - d) / d_{max};

  $totalmass = intensity = A * waste/26.0 * people * frequency$;

  $F_{intensity}$ = *impact* = normalise(*intensity*) between 0 and M_{thres};

Algorithm 5.9: WasteCollectionFromSource (*containers*, *houses*)

Input: layer *containers* (points; attribute $frequency$), layer *houses* (polygons; attribute *people*), $frequency_{bringingwaste}$ = 2, $distance_{year}$ = 29100.0 m, *waste* = 92.0 kg, *rho* = 400 kg/m^3, *size* = 4 m^3, *willingness* = 0.3

Output: layer *containers_waste_impact* (points; attributes *totalmass*, *intensity*, $F_{intensity}$, *impact*)

d_{max} = $distance_{year}$ / (52.0 * 2.0 * $frequency_{bringingwaste}$);

QGIS Buffer: *containers* with radius d_{max} //Euclidean distance used for current implementation;

QGIS Count Points in Polygon Weighted: *people* assigned to *container*;

$M_{thres} = \rho * size$;

for *container in containers* **do**

  A = 1.0;

  $totalmass = intensity = A * waste/26.0 * people * frequency$;

  $F_{intensity}$ = *impact* = normalise(*totalmass*) between 0 and $M_{thres} * frequency$;

5.3.14 The Boundary Problem

As described in Chapter 2, the Boundary Problem can occur when the area of impact is larger than the area of interest. When modelling impact spatially from a source perspective, a bias might occur in case a part of its area of impact is ignored due to its proximity to the boundary of the area.

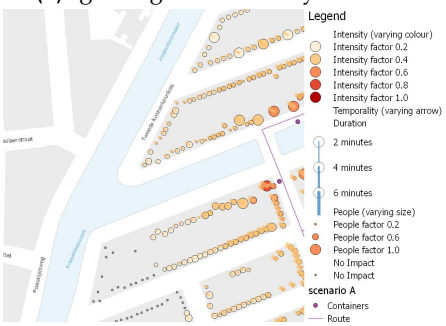
The boundary problem is, for this geographical case, solved by using a buffer for the analysis, as described in Chapter 2. When assessing impact by sources in a certain area of interest, all possible receptors within the buffer around the area of interest are maintained. When assessing the impact at receptors on the other hand, all sources within the buffer around the area are maintained.

The buffer radius is set to 500 meters around the area of interest. With this radius it is expected that all relevant features are maintained. For example, the noise impact is, amongst others, defined by the noise source level and the noise nuisance threshold. The larger the difference between the two is, the further the impact spreads. However, 500 meters is assumed to be a suitable radius.

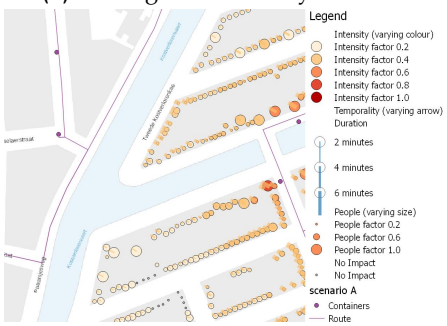
In figure 5.25, the difference between ignoring the boundary problem and solving it using a buffer is shown for the Receptor modelled impact of the Noise impact indicator. It can be seen that when solving the boundary problem using a buffer as visualised in figure 5.26b, houses along the water are influenced by containers at the other side of the water: some houses which are found to have no impact when ignoring the boundary problem do have impact when the boundary problem is addressed. In addition, some houses which are found to be affected for a duration of only 2 minutes when ignoring the boundary problem are found to be affected for 4 of 6 minutes when the boundary problem is addressed.

Figure 5.25: The Boundary Problem: difference between ignorance and use of the buffer solution for receptor modelled noise impact

(a) Ignoring the Boundary Problem



(b) Solving the Boundary Problem



5.4 AGGREGATION AND VISUALISATION

In order to allow decision makers to use the outcomes of the spatio-temporal method, the outcomes should be readable. Since the method models 5 indicators using 11 factors, most of them from 2 perspectives, the information could be visualised in many different maps. However, this was not deemed readable and therefore not fitting the purpose of the method. In order to maintain readability of the outcomes, two aggregation approaches were tested: firstly factor aggregation, aggregating the values and factors into 1 aggregated value per impact indicator, resulting in 5 maps, and secondly visual aggregation, presenting all factors and values per impact indicator in one map.

5.4.1 Value Aggregation

Three ways to aggregate the three factors of the noise, odour and congestion impact into one value were tested.

In figure 5.27 three maps show the normalised intensity factor (figure 5.28a), temporality factor (figure 5.28b)and affected population factor (figure 5.28c).

Firstly, the WP aggregation method was used, essentially multiplying the three factor values into an aggregated value. This method is shown in figure 5.30a. Secondly, the combination of Boolean multiplication and the SAW aggregation method was used, setting the aggregated value to 0 in case one of the factor values is 0 and taking the average as aggregated value otherwise. This method is shown in figure 5.30b. Thirdly, Boolean multiplication is applied followed by taking the maximum

Figure 5.27: Normalised intensity, temporality and affected population factor values before aggregation

Figure 5.29: Aggregation of intensity, temporality and affected population factor into one aggregated impact Value: difference between 3 aggregation methods

of the three factors, resulting in an aggregated value of either 0 or the maximum factor value. Figure 5.30c shows the outcome of the third method.

From figures 5.27 and 5.29, it can be concluded that differences between the three aggregation methods are large. The WP aggregation method, as shown in figure 5.30a, gives only very low values and therefore hard to interpret, due to its multiplication of values between 0 and 1. The second method, Boolean multiplication and SAW aggregation, shown in figure 5.30b, maintains the variance in values and does maintain the scale of values to a larger extent. The pattern of higher impact values around sources, based on the higher intensity values at those locations, is maintained while taking into account the spatial variance patterns of the other factor values. The third method, Boolean multiplication and maximum value can be seen in figure 5.30c. This figure is very similar to the affected population factor visualisation, since maximum values of houses are for this sample often found in the affected population factor. The pattern of higher intensity values around impact sources can hardly be found after using the third aggregation method.

The second aggregation method of Boolean multiplication and SAW aggregation is therefore most satisfying. However, with all aggregation methods, many calculated impact details are lost. In addition, all aggregation methods ignore the scale difference amongst the values. Therefore, it was chosen to avoid aggregation of factor values as far as possible.

5.4.2 Visual Aggregation

Tests were performed to visualise all calculated values for one Impact Indicator within one map (i.e.for Noise Impact: Intensity, Temporality split in Moment, Duration and Frequency, Affected Population). This was done by using QGIS markers based on variables.

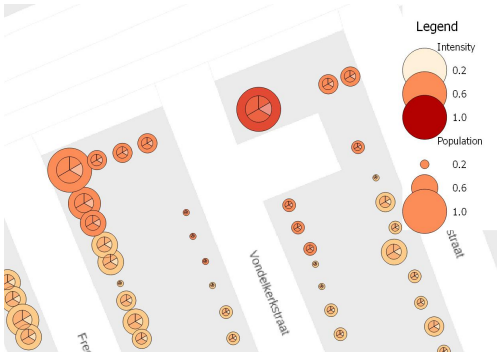
Both marker designs tested use the same principle to visualise Intensity and Affected Population values. The Intensity value is visualised in colour, within a range of five different colours from light orange to dark red. The affected population is visualised in the size of the marker. Due to these choices, the marker seems

insignificant in appearance in case either the intensity is very low or the affected population is very small compared to the threshold values. Both markers are round. For temporality values, two approaches were tested.

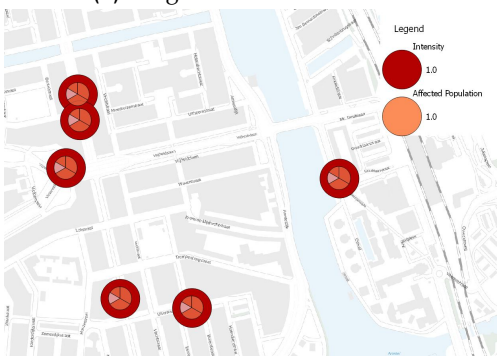
Firstly, temporality was visualised using its normalised values for Moment, Duration and Frequency Impact, i.e.the values resulting from the temporal curves. These values were shown in a pie chart diagram which was projected over the round marker. The size of the diagram is 60% of the size of the round marker itself. Each third of the diagram visualises a different temporality value. The marker shows the temporality value in orange and its rest part in white (i.e.if the moment value is 0.2, the first third of the pie chart is 20% orange and 80% white, then orange for the duration value and white for its rest part, etc.). Figure 5.32b shows the diagram marker applied to Noise sources. Due to their Boolean intensity calculation, these markers do not vary in colour. Variation in time is present, but does not become visual in the diagram due to the temporal curve interpretation. Figure 5.32a shows the diagram marker for Noise receptors. Clear difference can be seen in intensity and affected population, while time is rather constant due to the proximity of the houses to the same source.

Figure 5.31: Diagram markers visualising all 5 factor values for noise impact indicator

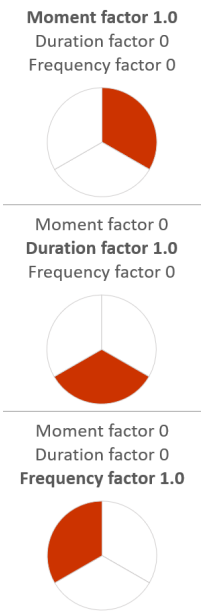
(a) Diagram marker at receptor



(b) Diagram marker at source

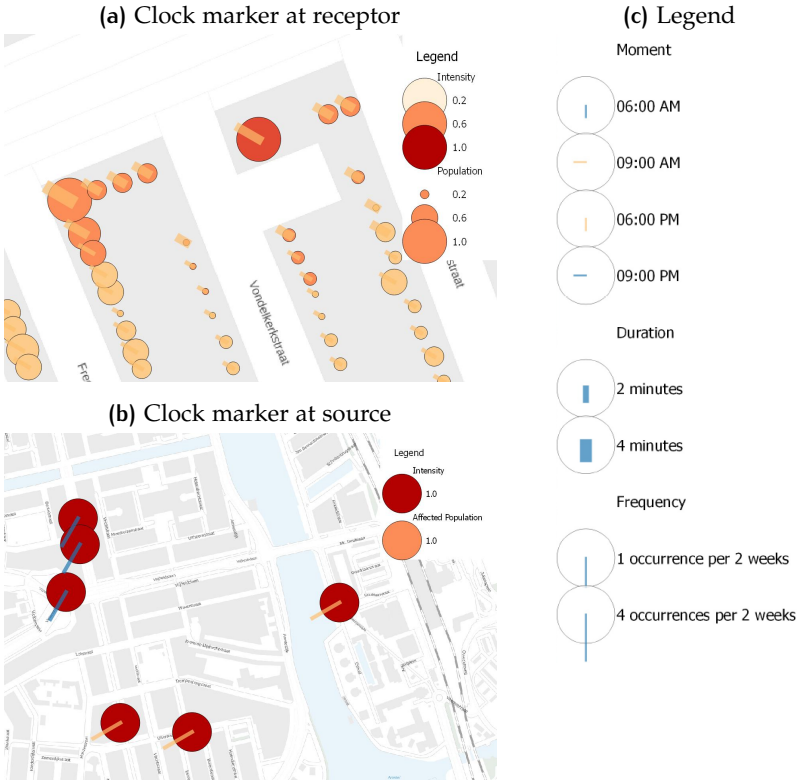


(c) Legend



Secondly, temporality was visualised using the principle of a clock. The moment in time is visualised in the rotation of clock arrow like line. For night time values, the arrow is blue, while daytime values are shown in yellow. The width of the arrow represents the number of minutes the impact lasts while its length represents the frequency of the impact. Figure 5.34b shows the clock markers for the same noise sources. In contrast to the diagram markers, the differences in moment in time between the containers can now be read. Figure 5.34a shows the clock markers for the same noise receptors, where next to differences in size and colour clear differences can be seen in the width of the clock arrow, representing the duration of impact at the source.

Figure 5.33: Clock markers visualising all 5 factor values for noise impact indicator



It was concluded that the diagram markers are less intuitive to read. In addition, they only show normalised values and not the values itself. The Intensity dependent colour of the marker is largely covered by the fixed pie chart cover. Colours of the pie chart could not be made dependent on variables. The clock markers are more intuitive to read and in addition, they show the actual temporal values instead of normalised interpretations. However, the clock markers do need an elaborate and clear legend in order to maintain readability.

Final visualisations are made using clock markers and using a grey dot in case one of the factor values is 0.

5.4.3 Spatial Aggregation

The purpose of the method is to assess impact on a spatial granularity level which is consistent with the spatial granularity level of the impact source and impact receptor data. Therefore, impact is assessed at house, container and road segment.

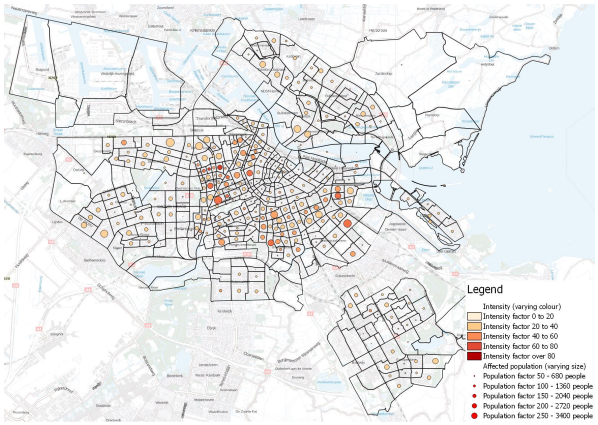
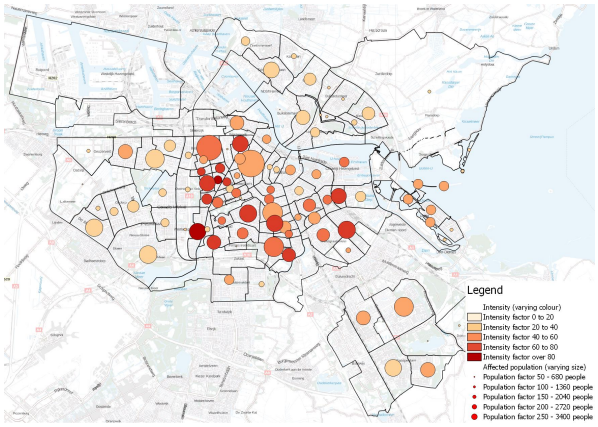
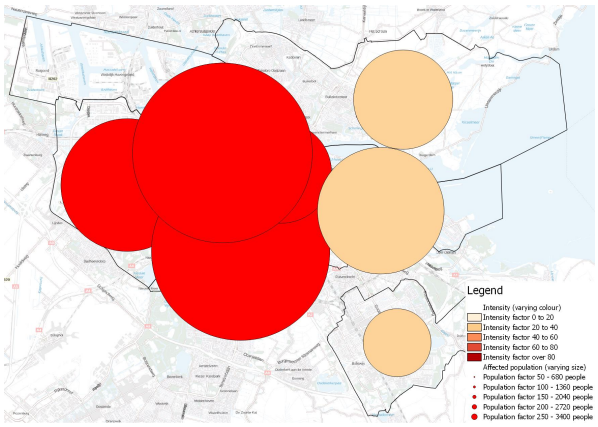
However, difficulties occur in interpretation of the assessment outcomes in case the extent of the area of interest (i.e.the extent of the scenario to assess) is big: impact markers become so small they are not readable. This problem is bigger for receptor modelled impact than it is for source modelled impact, since the receptor markers are more and therefore smaller than the source markers.

SPATIAL AGGREGATION LEVELS In order to maintain readability, the choice was made to test different spatial aggregation levels. The outcomes of the spatial aggregation serve as an addition to the non-aggregated outcomes (i.e.the houses, containers and road segments): in case of a large scenario extent and a small visualisation scale impact is visualised in spatially aggregated areas. When zooming in to a larger scale, area outcomes are replaced by outcomes of individual entities.

Table 5.4 shows three levels of spatial aggregation: aggregation to 455 neighbourhoods (in Dutch *buurten*), aggregation to 98 larger neighbourhoods (in Dutch *wijken*) and aggregation to 7 city parts (in Dutch *stadsdelen*). Spatial aggregation was performed using the QGIS tool Join Attributes By Location.

Note that the choice was made not to address the MAUP question for this Thesis. However, for visualisation purposes when spatially aggregating, the variant areas of the spatial entities might influence the interpretation of outcomes.

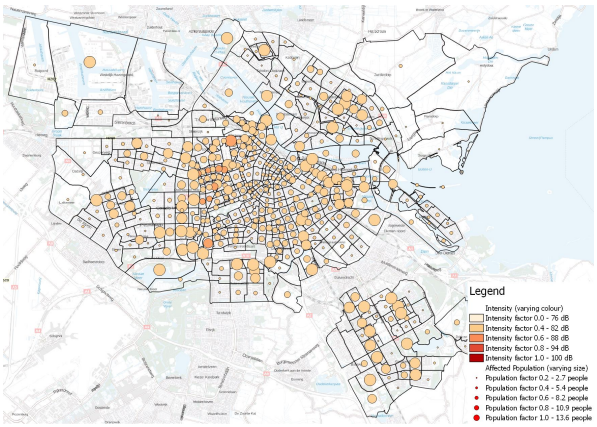
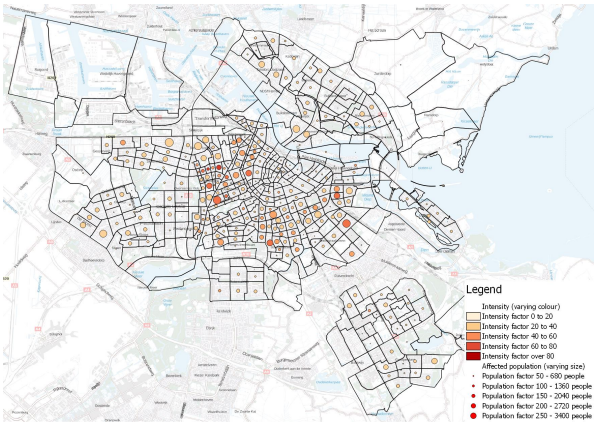
Table 5.4: Spatial aggregation of noise intensity and affected population totals

Aggregation Area	Figure
Spatial Aggregation to 455 Neighbourhoods (*buurten*) using total values: high variation in intensity and affected population; high spatial granularity; aggregated areas can be linked to individual features due to high granularity	
Spatial Aggregation to 98 Neighbourhoods (*wijken*) using total values: high variation in intensity and affected population; medium spatial granularity; some link between individual features and aggregated areas	
Spatial Aggregation to 7 City Parts (*stadsdelen*) using total values: no meaningful visualisation: low variation in intensity and affected population; very low spatial granularity; weak link between individual features and aggregated features	

SPATIAL AGGREGATION VALUES: AVERAGES AND TOTALS In the spatial aggregation, two ways can be used to aggregated values: averages, taking the average value of all spatial entities within the aggregation area, and totals, summing the values of all spatial entities within the aggregation area. The purpose of spatial aggregation is to allow the decision maker to identify areas of interest to zoom in to.

Table 5.5 shows both options and a short description to them. Spatially aggregating using total values fits the purpose best, since it maintains variance. However, use of totals does require further development of the clock markers in their representation of the temporal factors, to address the problems resulting from summing moments.

Table 5.5: Usage of averages or totals for larger neighbourhood areas (*wijken*)

Aggregation Value	Figure
Average values of receptors (i.e.houses) within larger neighbourhood: low variance; differences not directly clear; allowing for relative comparison of neighbourhood rather than of scenarios to each other	
Total values of receptors (i.e.all houses) within larger neighbourhood: high variance; clear differences allowing for identification of areas of interest to zoom in to; allowing for comparison of scenarios to each other	

Note that the average values are still normalised from 0 to 1, while the total values are not. However, the moment attribute cannot simply be averaged or summed: since it is temporal a meaningful outcome cannot be generated. Also, adaptations dependent on the values might have to be made for total values of duration and frequency. However, in case similar ranges for visualisation are used (for example colour from beige to red applied to average values from 0 to 1 and applied to total values from 0 to the feature count), patterns are the same.

For all other attributes, both the average and total can be spatially aggregated and calculated using the QGIS Join Attributes By Location Tool, by setting the mode for multiple features to either 'mean' or 'sum' and using a set of polygons to which spatial entities are to be aggregated.

5.4.4 Non-Spatial Graphs

When outcomes are aggregated to city level, only one average or total impact value for the whole city is maintained: this level of spatial aggregation results in Non-Spatial presentation of outcomes.

These Non-Spatial outcomes are visualised in graphs and serve for comparison to evaluate the added value of a non-spatial way to assess impact compared to the spatial assessment proposed in this Thesis. Note that both the spatial and non-spatial outcomes are calculated with the same spatial variables and methods, but their presentation differs.

When visualising the impact outcomes in a graph, the choice has to be made whether to visualise averages or totals. Following the choice to use totals for spatial aggregation, the obvious choice seems for use totals for the graphs as well. However, this raises difficulties when representing for example noise receptors and congestion receptors in the same graph: they differ in type (i.e.houses vs. road segments) and therefore in feature count and are therefore not comparable on the same scale when using totals. Therefore, the source based outcomes were visualised using average values as well.

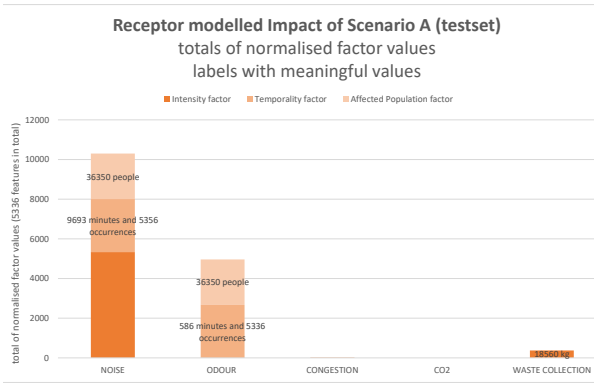
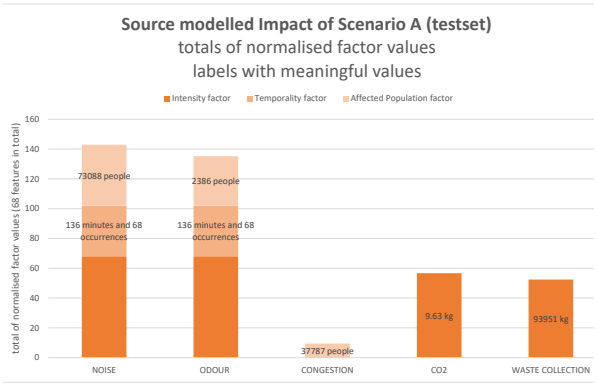
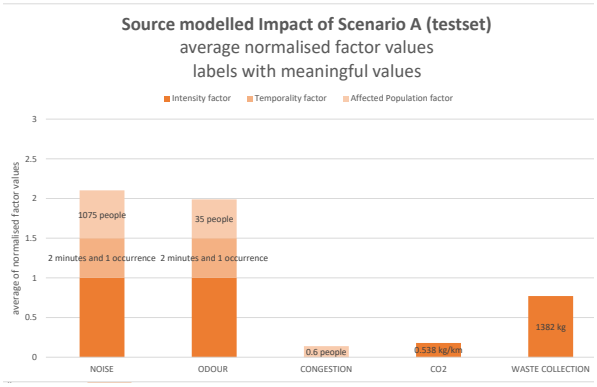
Table 5.6 shows the outcomes of the impact assessment in a non-spatial way: a graph. The bars in the graph represent the total of normalised factor values. The labels in the bars provide additional information on meaningful values. The graphs can be compared with the spatial representation of outcomes as appended in appendix E.

NON-SPATIAL WASTE TOTALS From the graphs in table 5.6, difference can be seen between the source and receptor calculation of the total mass of collected organic waste. The source based calculation of scenario A using the test set data has an outcome of 9,951 kg while the receptor based calculation has an outcome of 18,560 kg. However, when the receptor based calculation is performed with Boolean intensity values similarly to the source based calculation, the outcome is 37,164 kg. Still, the difference is large: 56,787 in number and a factor 2.5.

The only possible explanation found for this difference is that a container (i.e.source) assumes that all people within its reach will bring their waste to him. A house (i.e.receptor), on the other side, chooses the closest container to bring its waste to. Scenario A has many containers, and the waste collection range of containers is often overlapping. Waste of one house can therefore be counted multiple times by the containers.

When we find the corresponding numbers for scenario B, the difference is smaller: source based Boolean calculation yields a total of 9,254 kg while the receptor based Boolean calculation results in 10,126, with a difference of 872 kg (factor 0.9), but now with a larger outcome for the receptor based calculation. Scenario B has a lower amount of containers and almost no overlap in waste collection range. The difference here might be caused by small calculation or rounding errors. However, to support this hypothesis experiments with more different datasets would be needed.

Table 5.6: Non-spatial visualisation of outcomes in a graph

Type	Graph
Receptor based totals: receptors are houses and road segments, which are not equal in number therefore scale does not fit both; no value for CO_2 Emission Impact; very low vales for Waste Collection and Congestion Impacts; average intensity value for odour very small.	
Source based totals: sources are both containers and road segments, which are not equal in number therefore confusing scale; values for all indicators; readable outcomes;	
Source based averages: use of averages maintains scale; values for all indicators; readable outcomes	

6 RESULTS AND ANALYSIS

This chapter presents all results of experiments and implementation as described in the previous chapter. To discuss the results, tables are used, to which elaboration in text is given when relevant. The chapter is divided into four sections: the results on factor quantification; results concerning the spatial point of view in impact assessment; results on aggregation of outcomes of the method; and results on validation of the the added value of the spatial against non-spatial presentation of outcomes. The aim of this chapter is to present all results relevant to answer the research questions.

6.1 FACTOR QUANTIFICATION

Results on factor quantification are divided into four parts: intensity factor modelling, temporality factor modelling, affected population factor modelling and the boundary problem. Each factor is described per indicator according to its relevance for the method, its limitations and its main improvements identified. The solution to the boundary problem is described in its relevance, limitations and possible improvements as well.

6.1.1 Intensity Factor

Table 6.1 provides an overview of intensity factor results. For each indicator, corresponding results are divided into relevance, limitations and possible improvements. Some elaboration on these results in given in text.

The simple principle to model the intensity of noise (i.e.the formula based on distance and constants) provides spatially variant outcomes, which illustrates the relevance to model noise intensity spatially. However, the influence of noise shading by building to the way noise spreads is large. Extending the method with variable shading by buildings based on density values could improve the accuracy of its outcomes.

For odour intensity modelling, a similar simple principle using distance and constant values was used. Based on the outcomes, questions can be raised on the impact of odour caused by waste containers, since it seems to be occurring only very locally. However, this should be verified. With the assumed values for odour emitted by a container and the odour nuisance threshold, the impact range of odour is very short: only very few receptors are close enough to be affected. For this reason, it is hard to interpret the receptor noise impact: receptors with higher intensities are few and hard to identify. For sources, this is easier.

Congestion intensity values can directly be calculated by dividing road load by road capacity as given by the VMA roads dataset. For sources, they can be directly applied. For receptors however, the spatial spread of congestion impact over the network is very relevant. The current implementation of congestion spread is very rough, only using default speed values and not taking into account the character of the network (for example presence of crossroads). The receptor view challenges raise questions for the source side as well: is it good enough to only assess the direct neighbourhood of a container for its congestion impact. A more sophisticated model is therefore expected to change the outcomes for specific cases significantly.

Table 6.1: Summary table on intensity factor results

Component	Topic	Result
Noise Intensity	Relevance	Highly spatially variant for receptor, simple modelling method is sufficient
	Limitations	Only spatially variant at receptor
	Improvements	Method can be refined by including variable building shading for example
Odour Intensity	Relevance	Can only be determined after verification (see improvements)
	Limitations	Only spatially variant at receptor; current variable values and method yield very short impact range, therefore hard to interpret outcomes at receptor
	Improvements	Verification of values and method applicability should be done
Congestion Intensity	Relevance	Intensity highly spatially variant; with current scenarios and data only few containers found with high intensity value; spatial spread of congestion gives interesting outcomes at receptor
	Limitations	Spatial dimension highly interlinked with temporal dimension causing dependency issues; spatial spread of congestion not included from source
	Improvements	Spread of congestion over the network should be refined by incorporating traffic flow and speed in case of congestion
CO_2 Intensity	Relevance	Only calculation from source spatially relevant
	Limitations	Not applicable at receptor; outcomes very low in spatial variance
	Improvements	Further exploration of non-spatial presentation of outcomes in coherence with spatial presentation of outcomes of other factors
Waste Collection Intensity	Relevance	Accessibility and total amount of waste very relevant to calculate and present spatially
	Limitations	Outcomes are affected by snapping and joining thresholds
	Improvements	Implement using road network dataset complete for bikes and pedestrians

Also, congestion intensity is highly interlinked with congestion temporality: intensity and spread is dependent on moment and duration.

CO_2 Emission is a global impact and can therefore only be spatially modelled from the source side. For calculation of CO_2 Emission, the spatial approach is relevant: it is directly linked to distance, spatial sequence (i.e.increasing load over the route) and spatially varying speed. However it yields outcomes which are very low in spatial variance. Therefore, it seems that spatial presentation of outcomes does not add value over non-spatial presentation (i.e.numbers or graphs).

For waste collection intensity (i.e.accessibility of containers), the principle to calculate distance is very straightforward: accessibility is calculated as a rate between 0 meters distance and the furthest acceptable distance of 141 meters. However to implement it, reliable outcomes can only be found when using network instead of Euclidean distance calculations. This stresses the importance of spatially calculating and visualising waste collection impact. Existing QGIS and GRASS GIS tools are able to model accessibility over the network, but as currently implemented, not for all receptors and accessibility value could be calculated due to the usage of QGIS tool Join By Location. Snapping of points to the network in the network calculations affects the outcomes. To perform network calculations for accessibility, a dataset should be available which is complete in all roads and passages for bike and foot: next to main roads is should also include for example small or unpaved paths, squares or other open spaces and pedestrian short cuts, crossings and underpasses.

6.1.2 Temporality Factor

Table 6.2 provides an overview of temporality factor results. For each indicator, corresponding results are divided into relevance, limitations and possible improvements. Results are also given for aggregation of temporalities moment, duration and frequency. Some elaboration on these results in given in text.

For noise, the moment at which impact occurs is very relevant from a spatial point of view, since the scenario is spatio-temporal in character. Duration is only spatially varying from the receptor side: the dummy scenarios are not varying in duration. Duration at source side is therefore only relevant in case real scenarios are varying in duration of emptying containers. At the receptor side, involvement of duration values is very relevant. For frequency, values do not vary within the dummy scenario either. Only if frequencies vary spatially in real scenarios or if separate occurrences of noise impact are treated as increase of frequency (i.e.2 minutes of noise in the morning and 2 minutes of noise in the evening resulting in 2 minutes of noise occurring twice, instead of 4 minutes of noise occurring once), spatial presentation of outcomes is needed. If not, frequency can also be treated as a non-spatial value.

For odour temporalities, the same results apply as for noise. Additionally, odour is now assumed only to emerge when a container is emptied. Continuous emission of odour by the closed container is interesting from a temporal point of view: exposure to odour is expected to be longer, can be made dependent on wind frame frequencies and can even be made dependent on emptying frequency (i.e.fresh waste smelling different from rotten waste). However as described in the previous subsection, odour intensities are already very low and therefore local. Odour emitted by a closed container is expected to be even lower and therefore more local. A decision on the value of extending these temporality concepts can only be done after the intensity calculation is verified.

For congestion, the moment is already taken into account in the intensity calculation as well. However, visualisation of the moment as a separate value does add value for interpretation of outcomes. Duration only varies at the receptor side: in both the duration of the impact and in the spatial spread of impact over the network. Again, the frequency value is constant within each scenario. Only if impact occurrences at significantly different moments in time are treated to increase frequency

Table 6.2: Summary table on temporality factor results

Component	Topic	Result
Noise Temporality	Relevance	Moment is spatially variant; duration variant at receptor
	Limitations	Only closest source determines moment and frequency at receptor; duration not variant for sources
	Improvements	Make frequency at receptor dependent on presence of multiple sources and their moments; verify and calibrate weight curves
Odour Temporality	Relevance	Moment is spatially variant
	Limitations	One receptor rarely affected by multiple sources due to short intensity range; duration and frequency at receptor therefore rarely spatially variant; duration and frequency at source not spatially variant
	Improvements	Verification and calibration of values, weight curves and method applicability should be done
Congestion Temporality	Relevance	Moment relevant for spatial intensity calculation; duration defines spatial spread
	Limitations	Only closest source determines temporalities at receptor; frequency not spatially variant at source or receptor; Temporal dimension highly interlinked with spatial dimension causing dependency issues
	Improvements	Make frequency and duration at receptor dependent on presence of multiple sources and their moments; verify and calibrate weight curves
Aggregation of sub factor temporalities	Relevance	Loss of transparency but gain in overview; weight curves suffice; mandatory in case of factor aggregation, but should be avoided if not
	Limitations	Normalisation related to impact significance
	Improvements	Verify and calibrate weight curves

instead of duration, or if scenarios are used which are spatially variant in frequency, spatial representation of frequency is relevant.

6.1.3 Affected Population Factor

Table 6.3 provides an overview of affected population factor results. For each indicator, corresponding results are divided into relevance, limitations and possible improvements. Some elaboration on these results in given in text.

Table 6.3: Summary table on affected population factor results

Component	Topic	Result
Noise and Odour Affected Population	Relevance	Highly spatially variant
	Limitations	Uncertainties in determining population per receptor in data processing
	Improvements	Refine by including vulnerability of population based on characteristics such as age
Congestion Affected Population	Relevance	Highly spatially variant
	Limitations	Spatial dimension highly interlinked with temporal dimension causing dependency issues
	Improvements	Refine by finding and including population characteristics

Number of inhabitants per house is based on assumptions in data processing. This uncertainty was not to be addressed within the scope of the research but is still present. The affected population factor is spatially variant and therefore spatially relevant. Also the normalisation threshold for the affected population factor, needed in case of factor aggregation and for visualisation, is directly related to the spatial character of the data and noise variables. This makes the threshold apt for any receptor dataset. However, aggregated values or visualisations of different datasets cannot directly be compared: two scenarios can be compared only if the context data (houses) is constant.

For odour, modelling principles are very similar which increases the transparency of the method as a whole.

The affected population factor for congestion is also directly coming from the data: the VMA roads dataset. The affected population factor is very much spatially relevant, since congestion can only occur in case of many vehicles, which automatically means many people. Large spatial differences are found within the dataset. For congestion, a direct relation between intensity, temporality and affected population is present in the assessment method: for example intensity being dependent on moment and load (i.e.people). Although transparency is gained by maintaining all three factors individually, interrelation of factors means they cannot be aggregated without acknowledging their dependency.

6.1.4 Boundary Problem

Table 6.4 provides an overview of results concerning the boundary problem, divided into relevance, limitations and possible improvements. Some elaboration on these results in given in text.

A boundary problem occurs when only data in the area of interest is used to assess impact: impact caused within the area of impact but received outside of it, or

Table 6.4: Summary table on results concerning the boundary problem

Component	Topic	Result
Buffer Solution	Relevance	Solves too low estimation of factor values at spatial entities along boundaries of assessed area
	Limitations	Data should be available for assessed area as well as buffer zone
	Improvements	None identified

vice versa, is ignored and therefore results in a bias. This problem can occur with all spatial operations, both from the receptor point of view and from the source point of view. It increases when the area of interest is small compared to the range of the impact. For the case, the bias causes impact to appear less than it is, for instance in their intensity or their duration.

The boundary problem can be solved by the Buffer Solution: a buffer zone of data around the area of interest. For example when assessing noise from the source, the container dataset should cover the area of interest, while the dataset with houses the containers affect should cover the buffer zone as well. For the research, a buffer range of 500 m makes a significant improvement compared to ignorance of the buffer area. This solution requires data to be available for this buffer zone as well.

6.2 SPATIAL POINT OF VIEW

Table 6.5 provides an overview of results concerning the spatial point of view in impact assessment. For each impact indicator, it shortly discusses the relevance of assessing it from source and the relevance of assessing it at receptor. Some elaboration on these results in given in text.

Table 6.5: Summary table on spatial point of view results

Component	Topic	Result
Noise	Receptor relevance	Allows for variance in intensity, duration and frequency
	Source relevance	
Odour	Receptor relevance	Allows for variance in intensity, duration and frequency
	Source relevance	Clearer spatial variance of impact
Congestion	Receptor relevance	Allows for more variance in presentation of outcomes by including spatial spread
	Source relevance	Requires less elaborate calculation
CO_2 Emission	Receptor relevance	None: receptor is global
	Source relevance	Limited: low spatial variation
Waste Collection	Receptor relevance	Total amount of waste collected not biased by presence of multiple accessible containers
	Source relevance	Total amount of waste collected can be linked to capacity of containers

For each indicator, there is a relevance to model the impact from source. For most indicators, there is a relevance to model it at receptor as well: however for CO_2 calculation, no meaningful receptor calculations can be done.

For waste calculation, it was found that the total amount of waste differs significantly between the source and the receptor point of view. For example for scenario

A within the test set, the estimated total amount of waste which can be collected by the scenario is 2.5 times higher when assessed from source point of view than from receptor point of view. This is caused by the fact that the ranges of containers are overlapping while each single container assumes to be able to collect all waste within its range. Therefore the receptor calculation seems to represent reality better than the source calculation.

If one would want to make a choice whether to use the source or the receptor as a point of view for impact modelling, this choice would differ per indicator: CO_2 can only be calculated from source; the total value of separately collected organic waste seems to better represent reality when calculated at receptor; and variance in noise and odour intensity is only found when calculating at receptor.

However to maintain overview in interpretation and coherence in outcomes, the point of view cannot simply be swapped per indicator or factor. The spatial point of views provide different information in essence, both of which are expected to be of use for the decision maker. To allow a transparent decision making process, the information from both sides complements each other rather than it results in redundancy.

6.3 AGGREGATION OF OUTCOMES

Results concerning aggregation of outcomes are divided into three parts: value aggregation, visual aggregation and spatial aggregation. Each aggregation method or approach is described according to the extent with which is maintains information in the aggregation process, its transparency and the interpretation of its outcomes.

6.3.1 Value Aggregation

Table 6.6 provides an overview of results concerning aggregation of values into one value. For each aggregation method, corresponding results are divided into the topics information, transparency and interpretation. Some elaboration on these results in given in text.

Table 6.6: Summary table on results concerning value aggregation

Component	Topic	Result
WP	Information	Information lost; spatial variance pattern not maintained
	Transparency	Not transparent
	Interpretation	Hard to interpret due to low values and changed scale
Boolean & SAW	Information	Information lost; spatial variance pattern of values before aggregation maintained
	Transparency	Not transparent
	Interpretation	Interpretation easier due to maintained variance
Boolean & maximum	Information	Information lost: influence of all but one factor ignored; spatial variance pattern not maintained
	Transparency	Some transparency
	Interpretation	Hard to interpret due to high loss of information

All three value aggregation methods fulfil the requirement that outcomes of aggregation of factor values (i.e.intensity, temporality and affected population) should be such that in case one of the factors is 0, the outcome is 0.

One could argue that value aggregation allows for quick and convenient readability of outcomes and therefore could be of added value. However, this research adds the spatial dimension to impact assessment with a granularity coherent to the granularity of scenarios and context data, in order to allow for a transparent assessment. It is deemed contradicting to gain information and transparency on the one hand by adding the spatial dimension, while to lose information and transparency on the other hand by aggregating values.

Factor aggregation was therefore avoided within the final implementation of the method. Since no factors are to be aggregated, aggregation of indicators is irrelevant as well.

6.3.2 Visual Aggregation

Table 6.7 provides an overview of results concerning visual aggregation of values into one marker. For each marker type, corresponding results are divided into the topics information, transparency and interpretation. Some elaboration on these results in given in text.

Table 6.7: Summary table on results concerning visual aggregation

Component	Topic	Result
Size and colour	Information	Both normalised and meaningful values are maintained
	Transparency	Transparent
	Interpretation	Intuitive
Diagram markers	Information	Meaningful values are lost, normalised values maintained
	Transparency	Not transparent
	Interpretation	Not intuitive
Clock markers	Information	Both normalised and meaningful values are maintained
	Transparency	Transparent for actual values or averages, less transparent for totals
	Interpretation	Intuitive but requires elaborate and clear legend

To represent the affected population factor and intensity factor, the combination of varying colour and varying size fulfils the purpose. They both are intuitive to interpret. Moreover, if either of them is very low in value, and therefore impact is very low as well, the marker becomes very discrete. For all marker variables, a clear legend is essential to allow for meaningful interpretation.

6.3.3 Spatial Aggregation

Table 6.8 provides an overview of results concerning spatial aggregation of the values of individual spatial entities into a value for the whole area. For each aggregation area and each value type, corresponding results are divided into the topics information, transparency and interpretation. Some elaboration on these results in given in text.

Spatial aggregation is needed when assessing impact for the whole extent of the scenario: spatial granularity and number of individual spatial entities (i.e.in case of noise receptors over 100.000 individual entities) is too high to be visualised on a scale small enough to cover the whole city. The purpose of the method is to assess impact on a spatial granularity coherent to the spatial granularity of the sources and receptors. Spatial aggregation should therefore only be done in order to allow for visualisation and interpretation: to identify areas of interest for the decision maker

Table 6.8: Summary table on results concerning spatial aggregation

Component	Topic	Result
Small Neighbourhoods	Information	Values and variance maintained
	Transparency	Values do represent entities in area quite well
	Interpretation	Areas on screen when visualising city extent are small but readable, interpretation less convenient
Large Neighbourhoods	Information	Values maintained, some variance lost
	Transparency	Values represent entities in area to some extent
	Interpretation	Easy due to convenient area size when visualising city extent
City parts	Information	Values maintained but almost all variance lost
	Transparency	Values do not represent entities in area
	Interpretation	Easy but irrelevant due to large loss of information
Totals	Information	Meaningful and normalised intensity and affected population values maintained, temporality values currently lost in visualisation, spatial variance is maintained
	Transparency	Representative values
	Interpretation	Intuitive in visualisation but scale of values differs
Averages	Information	Meaningful and normalised values maintained, spatial variance lost, averages of receptor entities lower than averages of source entities
	Transparency	No representative values due to lack of variance
	Interpretation	Hard due to lack of variance

to zoom in to. On large scale the outcomes should be made available in full spatial granularity.

Total values allow for identification of areas of interest for further inspection of the impact assessment, while averages do not. However, further development of the clock marker as discussed in the previous sub section is needed in order to allow visualisation of total temporality values.

Average impact values of an area are significantly lower when presenting receptor values compared to when presenting source values. This difference can be explained by the fact that in general every source has an impact, while not all receptors receive an impact: for the test case a container always has houses in proximity but not all houses have containers in proximity.

Area values should be interpreted in correspondence to the character of the area: for example the interpretation of total affected population for an area should take into account whether the area is large and densely populated or small and sparsely populated. This problem corresponds with the MAUP, which is outside scope for this research, but should be acknowledged.

6.4 VALIDATION AGAINST NON-SPATIAL OUTCOMES

Table 6.9 provides an overview of results concerning the validation of the spatial presentation of outcomes against a non-spatial presentation of outcomes (i.e.presentation in a graph). For both presentation possibilities, corresponding results are described in the extent to which calculated information is maintained, its transparency for decision makers and the interpretation of its outcomes. Some elaboration on these results in given in text.

Table 6.9: Summary table on validation of spatial outcomes against non-spatial outcomes

Component	Topic	Result
Spatial presentation	Information	Information maintained
	Transparency	High
	Interpretation	Easy in case of clear legend
Graph presentation	Information	Lot of information on nuisance indicators lost, information on CO_2 indicator outcomes largely maintained, information on waste collection indicator lost but also added when presenting totals
	Transparency	Low due to choices made in what values to present (averages, totals), to present meaningful or normalised values, what entities and what scale to use
	Interpretation	Convenient due to low amount of information

When capturing all calculated data in a non-spatial way, a graph can be used. However, choices have to be made in the process: either to choose averages or totals, to visualise normalised factor values or actual values. In addition, total values of source based calculations as well as outcomes of receptor based calculations can only be included in the same graph when two different axes for the same dimension are used. The same accounts when visualising totals for receptors of all indicators in one graph, since they vary in type and therefore number (i.e.houses for noise and road segments for congestion).

This large amount of choices illustrates the challenge of communicating outcomes in a non-spatial overview. Each choice results in loss of a different but significant

part of information calculated. In addition, outcomes are presented in a very abstract way compared to the spatial presentation, resulting in less intuitive and less transparent interpretation of results.

Added value of presenting outcomes in a graph can be found in the global impact indicators CO_2 Emission and Waste Collection: as mentioned before, CO_2 impact is very low in spatial variance and therefore not relevant for spatial presentation of outcomes: not much information is lost by presenting the outcome as just a number, while simplicity in interpretation is gained.

Also for waste collection, knowing the total value of organic waste separately collected within the area of interest is valuable information which can easily be read from a graph. However for waste collection, the non-spatial graph is not deemed sufficient but only complementary: spatial outcomes such as where the waste is collected and which containers are used the most is valuable information which should not be lost.

7 CONCLUSIONS, DISCUSSION AND RECOMMENDATIONS

The final chapter of this thesis concludes the research by answering the research questions raised in Chapter 1. The chapter consists of three sections: a section with answers to all research sub questions followed by an answer to the main research question; a section with a discussion of the research; and a section with recommendations for future research.

7.1 CONCLUSIONS

As described in Chapter 1 the aim of this research is to answer the following main research question:

> *What spatio-temporal method is suitable to assess the impacts of organic waste collection system scenarios in Amsterdam?*

To this main research question, five sub questions were formulated. The following paragraphs answer these sub questions. Subsequently, an answer to the main research question is formulated.

SUB QUESTION 1 – TO WHAT EXTENT DO EXISTING IMPACT ASSESSMENT METHODS INCORPORATE SPACE? The extent to which existing impact assessment methods incorporate space is limited.

Methods aiming at assessing the impact of spatial planning scenarios are often spatial in calculation, but non-spatial in presentation and interpretation of outcomes. Outcomes are then presented and interpreted from graphs or tables. Examples of these are [Chang and Wang, 1997; Antunes et al., 2001; Schauberger et al., 2001].

Some methods are models of phenomenon intensity (i.e.modelling noise in dB or odour in OU_E/s) rather than models of impact, which, according to the impact definition used for this research, is more than the phenomenon causing it. Examples of these are [Sironi et al., 2005; Schauberger et al., 2001].

Models with a spatial component often model impact as a characteristic of the source, for example [Antunes et al., 2001], or as an effect on a receptor, for example [Gulliver et al., 2015]. No studies were found where this difference is explicitly acknowledged. Also no studies were found comparing or combining the two approaches.

According to the definition of spatio-temporal for this research, no spatio-temporal impact assessment methods were found. However, methods such as [Chang and Wang, 1997; Gulliver et al., 2015; Freeman and Cudmore, 2002] do involve both dimensions in their assessment and could therefore be regarded precedents of spatio-temporal impact assessment methods.

SUB QUESTION 2 – HOW CAN THE CHARACTERISTICS OF EACH IMPACT BE MODELLED SPATIALLY? Following the definition of impact, impact is a combination of a phenomenon caused by a source and a group which is affected by it. This research quantifies the first as Intensity Factor and the second as Affected Population Factor. Together they define the spatial characteristics of impact. Five impacts were relevant for the case: noise, odour, congestion, CO_2 and waste collection impact.

It was found that calculation of impact on both the receptor and the source side adds value to the outcomes: they complement each other in the information they

provide to the decision maker; and their combination makes the method more transparent. A decision maker can for example see why the affected population by a container is high by analysing the affected population at receptors as well. Understanding of outcomes is thereby enlarged, which raises their value, and insight is gained on where to possibly move a container in order to reduce nuisance or enhance waste collection.

Local impacts (for this research: noise, odour and congestion impact) can be spatially quantified by both intensity and affected population. The waste collection impact, a global impact, can be modelled in intensity of the phenomenon only, although affected population is indirectly included in calculation of intensity as well. The CO_2 emission impact, also a global impact, can be modelled by spatially quantifying intensity but does not require spatial presentation of outcomes, since the receptor is not variant over space.

To model the intensity of a phenomenon (i.e.in decibels, odour particles, congestion rates and kilograms), simple methods (such as the noise calculation method solely based on distance and constants) applied in space are sufficient to generate meaningful outcomes. These are available in existing research. However, they are highly dependent on assumptions for their input variables. In general, rather basic spatial analysis tools such as distance to nearest hub allow for implementation in few steps and short processing time.

For waste collection accessibility modelling, network calculations should be used to provide accurate outcomes, even though that increases processing time. For these calculations, a network dataset should be used which is complete in segments accessible by foot and bike: for example in foot and bike paths, squares and pedestrian crossings and underpasses.

Congestion modelling also requires network calculations. These calculations should use a dataset complete in roads for motorised vehicles and with directions of segments.

Modelling of the affected population can directly come forth from the available datasets: of the receptors (for this research: houses or road segments) an estimated number of people should be known. To calculate the population a source affects, basic spatial tools such as buffer and point count suffice.

SUB QUESTION 3 – HOW CAN TEMPORAL FACTORS BE INCORPORATED IN THIS SPATIAL MODEL? Temporal factors can be called Temporalities. Relevant temporalities for the case are: moment, duration and frequency of impact.

For temporalities, difference is made again between local and global impacts. For local impacts, temporalities are included in accordance with the temporalities of the scenarios. For global impacts, temporalities are included only indirectly: duration and frequency define the distance threshold for waste collection for example.

Due to the spatio-temporal character of the scenarios, basic analysis tools (such as distance to nearest and join by table) suffice to incorporate temporal factors in the impact model: impacts are then in spatio-temporal coherence with the scenarios.

For impact of a source, temporalities can directly be inherited from the spatial scenario being assessed. Duration and frequency are not spatially varying for source, since they are constant within each scenario.

For impact at a receptor, temporalities moment and frequency are inherited from the source which causes its intensity. For this research, this is the source closest in Euclidean space. The temporality duration is defined by the number of sources within range: based on their proximity in space, it is assumed their are in proximity in time as well, and therefore causing an impact which is continuously experienced over a longer duration. The frequency temporality could be made dependent on the proximity or sources which are not close in time, however this was not tested.

For congestion impact, temporalities are highly correlated to the spatial model: spatial intensity is dependent on the moment and duration defines the spatial spread.

SUB QUESTION 4 – HOW CAN AGGREGATION PRINCIPLES BE APPLIED TO INTEGRATE THE DIFFERENT SPATIO-TEMPORAL IMPACTS? When aggregating values, they should be normalised. Normalisation eliminates meaning from the values. Therefore, the actual (i.e.meaningful) values should always be maintained. Normalisation of intensity values can be done linearly between chosen thresholds, based on literature. Normalisation of temporality values can be done by using temporal curves, defining a value between 0 and 1 for each possible temporality value. Normalisation of affected population factor values can be done linearly between thresholds defined by the averages within the receptor datasets. When impact is non-existent, the normalised value is 0.

Factor aggregation of the three factors is only relevant for the local impacts. Factor aggregation should be such that if one of the factors is 0, the impact is 0. Three aggregation methods fulfilling this demand were tested on how they maintain spatial variance and allow for transparent interpretation of outcomes. Boolean multiplication combined with SAW scores best on this demand, but still insufficient. Therefore it was concluded that factor aggregation should be avoided.

Visual aggregation was tested as well: aggregation of the three factor values visually into one marker on the map, aiming at allowing transparent interpretation of outcomes while maintaining overview. A clock-like marker showing intensity in its colour, affected population in its size and the three temporalities in its clock like arrow was found to be sufficiently transparent and intuitive.

Factor values were used for visualisation together with their corresponding meaningful values in the legend. For example: for noise and odour, equally sized markers represent the meaningful affected population values (i.e.actual number of people) corresponding with their normalised affected population factor value of 1.

SUB QUESTION 5 – HOW DO THE OUTCOMES OF THE SPATIO-TEMPORAL ASSESSMENT METHOD COMPARE TO THE OUTCOMES OF SIMILAR NON-SPATIAL PRINCIPLES? Non-spatial outcomes are for the research defined as outcomes describing the whole area: one lumped region with no spatial variance of values within it. Non-spatial outcomes are therefore equal to the ultimate level of spatial aggregation possible.

There is a need to perform impact calculations spatially: this is amongst others illustrated by the importance of network calculations for accessibility; the double counting of collected waste by sources in proximity; and the influence of the boundary problem on outcomes. To maintain transparency for decision makers, calculations were presented on similar spatial granularity.

However, some level of spatial aggregation is needed in order to allow for intuitive and simple interpretation of data from small scale and city extent, while allowing to zoom in to large scale and individual sources and receptors. For each aggregation area, total impact values are visualised: for example the total population affected and the total duration of impact occurring. Average values were found not to be distinctive in spatial aggregation.

The non-spatial outcomes were visualised as totals in a bar chart. Use of such a chart causes loss of information, transparency and intuitive interpretation. In addition, difficulties occur when data from sources and receptors are all visualised within one chart. In some cases, information about the total number of CO_2 emitted or population affected by the scenario can also be added value.

The added value of quantifying impact for each individual source and receptor, and therefore the gain in information and transparency for the decision maker, is lost when visualising all data in a non-spatial manner. Non-spatial presentation of some outcomes can be complementary to the spatial ones, but only non-spatial description of the spatial impact of spatial planning scenarios is not sensible.

MAIN RESEARCH QUESTION – WHAT SPATIO-TEMPORAL METHOD IS SUITABLE TO ASSESS THE IMPACTS OF ORGANIC WASTE COLLECTION SYSTEM SCENARIOS IN AMSTERDAM? Given spatio-temporal scenarios consisting of container locations, routes and collection schedules and the usage of spatial houses, road network and neighbourhoods datasets, a suitable spatio-temporal method to assess impact of organic waste collection system scenarios should be as follows.

The method should assess impact from both sources (i.e.containers and route segments) and receptors (i.e.houses and road segments). For interpretation purposes, the impact of individual sources and at individual receptors has to be visualised at large scale as well as spatially aggregated to neighbourhood totals when visualised at small scale.

The method should quantify impact using five indicators: the local indicators noise, odour and congestion and the global indicators CO_2 emission and waste collection. All of those except for CO_2 emission should be visualised spatially.

For all indicators, the method should quantify the intensity factor of the impact using simple calculation principles and basic spatial tools. The intensity factor describes the phenomenon caused by the source, expressed in respectively decibels, particles, rates or kilograms.

For the local indicators, the method should quantify the affected population. The number of people is known at the receptor and can be accumulated to a source. In addition, it should calculate the temporalities moment, duration and frequency at which the impact occurs. The temporality factor values are available at the impact sources and can be inherited by the receptors.

After quantification, the method should normalise all factor values using meaningful thresholds. Factor values should not be aggregated into one value but into one marker on the map expressing all individual values at once. A clock like marker is able to do so.

The method should present non-spatial totals only as complementary information to the spatial presentation of outcomes.

7.2 DISCUSSION

ADDED VALUE TO THE FIELD OF GEOMATICS In general, the added value of this research to existing studies within the field of Geomatics can be found in its effort to convert a broad societal problem into spatial entities, indicators and factors with an important spatio-temporal component.

This research has tried to capture the abstract term *Impact* via its linguistic definition into a spatio-temporal method, allowing for implementation in GIS software and aiding decision makers in the practical problems they encounter. Via the linguistic definition of impact, the choice where to quantify impact has come forth: both from the causing (i.e.source) and at receiving (i.e.receptor) spatial entity. This is an approach which was not found in any of the related studies, but has proven to be an interesting and fruitful guideline throughout the research.

Added value can also be found in the calculation and presentation of impact indicator outcomes on a spatial granularity coherent to the spatial granularity of both the sources and receptors. Inherent to presentation of impact indicator outcomes on this granularity is the visual aggregation chosen: the information gained by impact assessment on high spatial granularity on the one hand should not be annulled by normalisation and value aggregation on the other hand.

This research has described local impact indicators in the factors Intensity, Temporality and Affected Population. These factors are believed to be applicable to many more impact indicators, for which this research can be regarded as an exploration of possibilities. An impact indicator such as light pollution for example could also be expressed in these factors. Using the currently implemented impact indicators Noise, Odour, Congestion, CO_2 Emission and Waste Collection in different arrange-

ment, impact of for example an open air festival or the impact of a weekly food market could be described as well.

Moreover, the method is currently implemented for the Municipality of Amsterdam, the Netherlands. In essence, the method could be applied to other areas as well. However, spatial aggregation areas should be chosen such that they fit the extent of the area and such that the values of areas represent the spatial variance of the values of individual entities (i.e.individual sources and receptors in the area). In addition, variable values, such as nuisance thresholds and wind speed, should be set to fit the new area.

THREE CRITICAL SIDE NOTES Some critical side notes to the research have to be made as well. Three main side notes are:

1. Firstly, many variable values had to be assumed in the quantification process. These assumptions cause uncertainty and therefore influence the reliability of the outcomes of the method. Many assumptions were made based on literature, of which the research case or purpose does not directly match the research in this thesis. Examples of assumptions from literature are: noise level and odour particles emitted when emptying an organic waste container; the nuisance threshold of noise level and odour particles; and the occupancy rate of vehicles.

   Other assumptions could not be based on literature and were therefore made based on experience and expectations. These assumptions cause an even higher uncertainty in the method. Examples for assumptions by experience are and expectations are: willingness rate of Amsterdam inhabitants to use an organic waste collection system; temporal weight curves (although to some extend based on literature as well); and the duration of emptying a container.

   The implementation in PyQGIS scripts is such that it allows for easy adjustment of variable values in case verification raises the need to adjust them.

2. Secondly, the quantification outcomes of factors were not verified or calibrated. To do so, both qualitative and quantitative measurements would be needed. For calibration, tests with real scenarios and complete data (i.e.the roads dataset for accessibility) are needed as well. To verify the significance of impact, a whole new field of research would have to be included. Lack of verification and calibration makes the outcomes method of less value for decision makers.

3. Thirdly, conclusions on the readability and intuitive interpretation of the spatially visualised outcomes of the method were not tested with users: they were only based on own experience and that of supervisors and fellow students. This leaves questions on the validity of conclusions linked to this part of the research, which should be answered before the method can be used by decision makers.

7.3 RECOMMENDATIONS

Coming forth from the results, conclusions and discussion of this research, some recommendations for future research can be made.

Difference is made between technical recommendations, concerning further development of the method and usability recommendations, concerning the way in which the method can be made usable by actual decision makers.

Five recommendations for future technical development of the method are:

1. Verify and calibrate the assumed variables and the outcomes of the calculations both quantitatively and qualitatively: for example the number of deci-

bels; the amount of CO_2 emitted; and the experience and significance of impact.

2. Improve accuracy of network calculations for waste collection accessibility by further developing the method as well as using road network data complete for foot and bike. Improve efficiency of the network calculations to allow for implementation on city extent.

3. Improve and extend the implementation of the spatial intensity modelling methods: for example to use variant building density for noise shading; to include a neighbourhood dependent waste collection willingness factor; to assess impact at receptor not based on nearest but on most affecting source; to improve accuracy of total amount of waste collected at source by avoiding double counting of the same household waste by multiple sources.

4. Improve and extend the implementation of impact temporality modelling: for example by improving the duration and frequency calculation at a receptor in proximity of multiple sources.

5. Address unsolved problems such as the MAUP and handling of inevitable uncertainties in the data.

Two recommendations to make the method usable for decision makers are:

1. Develop a user interface to the method, allowing decision makers for low key use of the method and its outcomes: for example a portal running parts of the method on demand; allowing direct inspection of decision makers without GIS experience; allowing for comparison of a scenario to a baseline situation or scenario; and allowing for interactive design of the spatio-temporal scenarios: composing and revising the scenario while assessing its impact.

2. Test the outcomes of the method and the way in which they are visualised with real users: decision makers on waste collection system planning in the municipality of Amsterdam.

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A METHODOLOGY

PHASE 1: PROBLEM IDENTIFICATION AND RESEARCH CHOICES

Data

- BAG Residences
- BAG Buildings
- CBS Neighbourhoods
- Traffic Model Amsterdam
- Municipal Waste Facilities

Tools

- QGIS
- GRASS GIS
- PyQGIS

1A. Existing assessment methods

Research existing methods for planning or impact assessment → Identify extent of their spatio-temporal possibilities → Define purpose of impact assessment method → Identify non-spatial impact assessment principle for comparison

1B. Impact assessment indicators and factors

Define impact indicators for assessment → Define factors to them → Define relative weights and compensatability → Research existing methods to quantify factors

1C. Context data

Define datasets needed and inventorise availability → Obtain datasets needed → Convert, clean and process them if needed → Visualise them if spatially

Setup QGIS project → Setup GRASS GIS plugin in QGIS → Setup PyQGIS scripts → Convert, clean and process them if needed

1D. Spatio-temporal planning scenarios

Define relevant practical requirements to planning scenarios → Define components and changeable factors of the scenarios → Generate spatial planning scenarios

Choose spatial structure for describing planning scenarios → Generate spatial planning scenarios

Answer sub question 1
To what extent do existing impact assessment methods inrocporate space?

PHASE 2: DESIGN

Iterate

2A. Components for assessment per indicator

Choose or develop concepts to quantify each indicator spatially → Perform small practical experiments

Choose or develop concepts to quantify temporal factors to each indicator → Perform small practical experiments

Perform small practical experiments → Develop spatio-temporal assessment method component to quantify each indicator

2B. Components for multi criteria assessment

Choose or develop multi criteria assessment principles → Perform small practical experiments → Develop multi criteria method component

Iterate

Answer sub question 2
How can the magnitude of each impact be modelled spatially?

Answer sub question 3
How can temporal factors be incorporated in this spatial model?

Answer sub question 4
How can multi criteria principles be applied to integrate the different spatio-temporal impacts?

PHASE 3: IMPLEMENTATION

3A. Implementation per indicator

implement spatial indicator components on scenarios → identify improvements

implement temporal indicator components on scenarios → identify improvements

3B. Multi-indicator implementation

implement multi criteria principles on sceanrios → identify improvements

PHASE 4: VALIDATION

4. Validation

Present method outcomes non-spatially → Validate added value of the spatio-temporal method

Validate alternative method components against purpose

Answer sub question 5
How do the outcomes of the spatio-temporal assessment method compare to the outcomes of similar non-spatial principles?

Answer main research question
What spatio-temporal method is suitable to compare the impacts of organic waste collection system scenarios in Amsterdam?

B DATASETS

B.1 PREPARATION OF DATASETS

BAG RESIDENCES The BAG residences dataset contains points for each residence unit (i.e.address). Per unit, it contains amongst others the function, status and date as attributes.

Input data: BAG Residences

1. Clip to extent of Amsterdam Municipality
2. Remove all points without living function: where value to attribute *Gebruiksdoel* does not include *Woonfunctie*
3. Remove all former residences: where value to attribute *Einddatum* is not *NULL*
4. Remove all unused residences: where value to attribute *Status* is not *Verblijfsobjectingebruik*

Output data: BAG Residences in Amsterdam currently in use and with living function

NEIGHBOURHOODS CBS data contains all neighbourhoods with as attributes information such as total number of inhabitants, number of inhabitants for five different age categories, population density, number of households, percentage of households with children and average household size.

Input data: CBS Neighbourhoods

1. Remove all Neighbourhoods outside Amsterdam: where *WK_NAAM* is not *Amsterdam*
2. Remove unnecessary attributes
3. Remove neighbourhoods only consisting of water: where value to attribute *Water* is *JA*
4. Remove neighbourhoods without inhabitants: where value to attribute *AANT_INW* is 0
5. Count number of Residences with living function per neighbourhood and store in attribute

Output data: Neighbourhoods in Amsterdam having inhabitants

BAG BUILDINGS The Dutch BAG building dataset is complete for the municipality of Amsterdam. It does not contain building types, but this information is available in the BAG Residences described earlier.

An OSM Buildings dataset is also available and complete in geometry. However it is quite incomplete in its building classes attribute data. Therefore, it is not of use for this project. Data from the Top10NL topographical dataset is available as well, but does not provide the classes in a useful way either.

Input data: BAG Buildings, BAG Residences

1. Clip to extent of Amsterdam Municipality

2. Remove all buildings with footprint smaller than 15 square metres (following Gulliver et al. [2015])
3. Remove all former buildings: where value to attribute *Einddatum* is not NULL
4. Remove all unused buildings: where value to attribute *Status* is not *Pandingebruik*
5. Check for overlapping and duplicate buildings using QGIS Topology Checker
6. Load into GRASS GIS with snapping threshold 0.1 to remove small overlaps
7. Use GRASS GIS cleaning tools pbol and overlay to remove large overlaps
8. Use GRASS GIS cleaning tools break and rmdupl to find duplicates
9. Use GRASS GIS tool overlay subtract to remove duplicates, followed by MMQGIS tool merge to merge the dataset with duplicate features subtracted with the former duplicate features again
10. Count number of residences with living function per building and store in attribute
11. Remove all buildings with 0 residences.

All buildings as present after following the above steps are considers Houses. Now the datasets Houses and Neighbourhoods are combined.

1. Include neighbourhood statistical data as attributes to houses: Join Attributes by Location
2. Assign number of inhabitants to each houses based on relationship house to neighbourhood: $Residences_{house} / Residences_{neighbourhood} * Inhabitants_{neighbourhood}$, float precision 3

Output data: Houses with inhabitants

TRANSPORTATION NETWORK The VMA dataset is a Municipal dataset [Municipality of Amsterdam and Department of Infrastructure Traffic and Transportation, 2015]. It is complete in roads accessible for motorised vehicles. It contains a wide range of transportation related attributes, such as speed levels, number of lanes, road capacities and a capacity value the number of cars and trucks. These are all given for morning rush hours, evening rush hours and regular hours. From the capacity and load data, a level of congestion during rush hours can be calculated. The dataset is a directional network, including the directions which are mandatory to follow for motorised vehicles.

Input data: VMA

1. Check for road types not accessible for waste collection vehicles: no inaccessible roads were included in the original data
2. Calculate traffic intensity per road segment for morning rush hours, evening rush hours and non-rush hours: $2 * Load_{truck} + 1 * Load_{passengercar}$, float with precision 3
3. Calculate congestion value per road segment for morning rush hours, evening rush hours and regular hours: $intensity/capacity$, float with precision 3

Output data: Amsterdam Road Network for waste collection vehicles with congestion levels.

B.2 VISUALISATION OF DATASETS

Dataset - Houses

Municipality of Amsterdam
Scale 1:60.000

Legend

Scenario B

- Containers
- Route

DATA

- Roads
- Houses
- Neighbourhoods

0 1 2 3 4 5 km

Dataset - Roads

Municipality of Amsterdam

Scale 1:60.000

Legend

Scenario B

- Containers
- Route

DATA

- Roads
- Houses
- Neighbourhoods

0 1 2 3 4 5 km

Dataset - Neighbourhoods

Municipality of Amsterdam
Scale 1:60.000

Legend

Scenario B

- Containers
- Route

DATA

- Roads
- Houses
- Neighbourhoods

0 1 2 3 4 5 km

Datasets - Roads, Houses and Neighbourhoods

Legend

Scenario A
- Containers
- Route

Scenario B
- Containers
- Route

DATA
- Roads
- Houses
- Neighbourhoods

Testset Extent
Scale 1:7.500

0 0.1 0.2 0.3 0.4 0.5 km

C SCENARIOS

C.1 GENERATION OF SCENARIOS

C.1.1 Manual Generation of Spatial Scenarios

GRASS GIS was used to calculate routes along these containers, using the Travelling Salesman principle approximating the fastest route along all containers with costs defined by travel time. For scenario A, one route was made per city part (7 in total), while for scenarios B one route for the whole city was made.

Next to GRASS GIS, experiments were done in pgRouting, a database analysis tool in pgAdmin. However, the outcome of this tool is a list of ordered points instead of a route. Therefore, it was of less use.

In some cases, not all containers could be accessed from the road network, resulting in an error. These containers were manually found and set to be ignored in the Salesman algorithm

Input data: containers (points) and roads (lines)

1. Load data into GRASS GIS
2. Topologically clean roads dataset
3. Link containers to road network using Net tool with threshold 500 meters, resulting in dataset with both roads and containers
4. Find number of containers using Category tool
5. Assign unique categories to each road using Category tool
6. Add table to dataset with columns for category, length, speed, forward travelling cost and backward travelling cost
7. Copy speed value from original roads dataset into database using To Database tool
8. Write length value in kilometers into database using To Database tool
9. Update forward and backward travelling cost in database with time value using Database Update tool: $length/speed * 60$
10. Apply Salesman algorithm to dataset using time travelling costs

Output data: route along given containers

C.1.2 Automated Generation of Spatial Scenarios

The PyQGIS script to generate spatial scenarios is appended in appendix D. Pseudo code is shown in Algorithm C.1.

In order to be able to use GRASS tools from the PyQGIS script, the GRASS extent has to be set within the script. In addition, care is needed when converting QGIS models to PyQGIS scripts when using GRASS GIS tools: the dots have to be taken out from the parameter names manually to avoid Python errors (i.e.change *outputs_GRASSV.NET.SALESMAN_1* to *outputs_GRASSSALESMAN_1*). This accounts

Algorithm C.1: SPATIALSCENARIO (*containers*, *roads*)

Input: layer *containers* (points), layer *roads* (lines; attribute *speed*)
Output: layer *route* (lines; attributes *sequence*, *mylength*, *mycost*), layer *containers* (points; attributes *sequence*, $cost_to_next$)

```
for point in containers do
    QGIS Field Calculator: joincat [str] = @rownumber;
for line in roads do
    QGIS Field Calculator: roadlength [m] = $length;
    QGIS Advanced Python Field Calculator: roadscost [s] = roadlength /
     (1000.0 * speed);
GRASS GIS v.net.salesman: route and sequencetable along all containers via
 roads using costs roadcost;
QGIS Join Attributes By Table: sequencetable (on category) with containers
 (on joincat);
QGIS Join Attributes By Location: route with roads;
for line in route do
    QGIS Field Calculator: sequence [int] = @rownumber;
    QGIS Field Calculator: mylength [meters] = $length;
    QGIS Advanced Python Field Calculator: mycost [seconds] = mylength
     / (1000.0 * speed);
```

for all usage of GRASS GIS tools via PyQGIS scripts in the implementation of this research.

The road dataset also includes an own attribute with the length and cost of each segment. However, since the script for temporalities gave some unexpected outcomes, the choice was made to calculate length and costs using QGIS to guarantee consistency.

C.1.3 Automated Generation of Temporalities of Scenarios

With the geometry and sequence of the containers and route segments known, temporalities can be calculated to them. These are: moments in time (i.e.when does the truck arrive at a given container or route segments, represented by a datetime object with hours, minutes and seconds), duration (how long does the truck take to pass the segment in a float value, how many minutes is the truck present at the container in an integer) and frequency (how often is the segment or container visited within a 14 day period in an integer). Note again that the duration of emptying a container is not taken into account in the moments in time (i.e.when one segment is finished at 09:10h and ends in a container, the container is emptied at 09:10h with a duration of 2 minutes until 09:12 but the truck also starts passing the next road segment directly at 09:10). This choice was made for computational reasons.

The PyQGIS script to assign temporalities to the scenarios is appended in appendix D. Pseudo code is included in Algorithm C.2. The script consists of two parts: calculating temporalities of containers and calculating temporalities of route segments.

However, both methods were not consistent in outcomes: the further along the route, the bigger the difference in moment in time between the containers and the route segments. In this error no pattern could be found and in addition, it occurred, dependent on the input data, to both sides: sometimes the corresponding route segments where visited later than the containers, sometimes vice versa. Consistency in length, time and travel cost calculation was checked and possible errors due to rounding were eliminated.

Since the difference could not be solved, the choice was made to assign each container the moment in time of a road segment in proximity by using the QGIS tool Join Attributes By Location, as done in line 19 in Algorithm C.2 and makes the code in line 15 lose its relevance.

In order to be able to assign all containers a moment in time, the threshold of this tool was set to 500 meters. For some containers, this has resulted in a wrong moment in time, since they were not matched to directly connected segments. However, for the development of the method this has no implications.

The choice to assign the moment of the route segments to the containers and not vice versa is made since the calculation of the moment of the containers is based on GRASS GIS costs and therefore a *Black Box*.

Algorithm C.2: TemporalScenario (*containers*, *route*)

Input: layer *containers* (points; attributes *sequence*, *cost_to_next*), layer *route* (lines; attributes *sequence*, *mylength*, *mycost*), $start_{schedule}$, $duration_{schedule}$, $frequency_{schedule}$

Output: layer *route* (lines; attributes *moment*, *duration*, *frequency*), layer *containers* (points; attributes *moment*, *duration*, *frequency*)

```
1  for each layer do
2      Convert to CSV;
3      Append columns moment, duration, frequency;
4      Sort on sequence;
5      if first feature then
6          moment = start_schedule;
7          duration = duration_schedule;
8          frequency = frequency_schedule;
9      else
10         if layer is route then
11             moment = moment[previous] + mycost[previous];
12             duration = mycost;
13             frequency = frequency_schedule;
14         if layer is containers then
15             moment = moment[previous] + cost_to_next[previous] ;
16             duration = duration_schedule;
17             frequency = frequency_schedule;
18     QGIS Join Attributes By Table: layer with CSV;
19 QGIS Join Attributes By Location: containers with route, threshold 500 m;
```

The spatio-temporal scenarios resulting from Algorithm C.2 were used for tests and implementation of the assessment method in the next sections.

C.2 VISUALISATION OF SCENARIOS

Scenario - Scenario B

Municipality of Amsterdam
Scale 1:60.000

Legend

Scenario B
- Containers
- Route

DATA
- Roads
- Houses
- Neighbourhoods

0 1 2 3 4 5 km

Scenario - Scenario A

Testset Extent
Scale 1:7.500

Legend

Scenario A
- Containers
- Route

Scenario B
- Containers
- Route

DATA
- Roads
- Houses
- Neighbourhoods

0 0.1 0.2 0.3 0.4 0.5 km

Scenario - Scenario B

Testset Extent
Scale 1:7.500

Legend

Scenario A
- Containers
- Route

Scenario B
- Containers
- Route

DATA
- Roads
- Houses
- Neighbourhoods

0 0.1 0.2 0.3 0.4 0.5 km

D SCRIPTS

The scripts for generation of spatio-temporal scenarios and assessment of spatio-temporal impacts written for this Thesis are accessible via https://github.com/rflteeuwen/ThesisScriptsFinal.

This folder includes PyQGIS [.py] scripts for:

1. spatial scenario generation (Algorithm C.1)
2. temporal scenario generation (Algorithm C.2)
3. spatio-temporal noise impact modelling from receptor side (Algorithm 5.1)
4. spatio-temporal noise impact modelling from source side (Algorithm 5.2)
5. spatio-temporal odour impact modelling from receptor side (Algorithm 5.3)
6. spatio-temporal odour impact modelling from source side (Algorithm 5.4)
7. spatio-temporal congestion impact modelling from receptor side(Algorithm 5.5)
8. spatio-temporal congestion impact modelling from source side(Algorithm 5.6)
9. spatio-temporal CO_2 impact modelling from source side(Algorithm 5.7)
10. spatio-temporal waste collection impact modelling from receptor side(Algorithm 5.8)
11. spatio-temporal waste collection impact modelling from source side(Algorithm 5.9)
12. spatial aggregation of spatio-temporal impact values

In addition, it includes QGIS styles [.qml] for all impact layers, both spatially aggregated to neighbourhoods and for individual sources and receptors.

E OUTCOMES

For all five impact indicators, outcomes are appended in the following sections. For all but the CO_2 indicator, outcomes are available from both the receptor and the source point of view. The order of appended files per impact indicator is:

1. Scenario B for the whole Municipality (aggregated to neighbourhoods)
2. Scenario B for test set area
3. Scenario A for test set area

E.1 NOISE IMPACT INDICATOR OUTCOMES

SCENARIO B

Outcomes - Noise Impact at Receptor by Scenario B

Municipality of Amsterdam
Scale 1:60.000

0 1 2 3 4 5 km

Legend

INTENSITY (varying colour)
- Intensity factor 0 to 20
- Intensity factor 20 to 40
- Intensity factor 40 to 60
- Intensity factor 60 to 80
- Intensity factor over 80

AFFECTED POPULATION (varying size)
- Population factor 50 - 680 people
- Population factor 100 - 1360 people
- Population factor 150 - 2040 people
- Population factor 200 - 2720 people
- Population factor 250 - 3400 people

Outcomes - Noise Impact at Receptor by Scenario B

Legend

INTENSITY (varying colour)
- Intensity factor 0.2 - 76 dB
- Intensity factor 0.4 - 82 dB
- Intensity factor 0.6 - 88 dB
- Intensity factor 0.8 - 94 dB
- Intensity factor 1.0 - 100 dB

TEMPORALITY (varying arrow)

Moment
- 03:00 AM
- 06:00 AM
- 09:00 AM
- 12:00 AM
- 03:00 PM
- 06:00 PM
- 09:00 PM
- 12:00 PM

Duration
- 2 minutes
- 4 minutes
- 6 minutes
- 8 minutes

Frequency
- 1 occurrence per 2 weeks
- 4 occurrences per 2 weeks

AFFECTED POPULATION (varying size)
- Population factor 0.2 - 2.7 people
- Population factor 0.4 - 5.4 people
- Population factor 0.6 - 8.2 people
- Population factor 0.8 - 10.9 people
- Population factor 1.0 - 13.6 people

NO IMPACT
- No Impact

Testset Extent
Scale 1:7.500

0 0.1 0.2 0.3 0.4 0.5 km

Outcomes - Noise Impact of Source by Scenario B

Municipality of Amsterdam
Scale 1:60.000

0 1 2 3 4 5 km

Legend

INTENSITY (varying colour)
- Intensity factor 1.0 - 1 container
- Intensity factor 2.0 - 2 containers
- Intensity factor 3.0 - 3 containers
- Intensity factor 4.0 - 4 containers
- Intensity factor over 4.0 - more than 4 containers

AFFECTED POPULATION (varying size)
- Population factor 0.5 - 879 people
- Population factor 1 - 1758 people
- Population factor 1.5 - 2637 people
- Population factor 2.0 - 3516 people
- Population factor 2.5 - 4395 people

Legend

INTENSITY (varying colour)

Intensity factor 1.0 - over 70 dB

TEMPORALITY (varying arrow)

Moment

06:00 AM

09:00 AM

06:00 PM

09:00 PM

Duration

2 minutes

4 minutes

6 minutes

Frequency

1 occurrence per 2 weeks

4 occurrences per 2 weeks

AFFECTED POPULATION (varying size)

Population factor 0.2 - 351 people

Population factor 0.4 - 703 people

Population factor 0.6 - 1055 people

Population factor 0.8 - 1406 people

Population factor 1.0 - 1758 people

No Impact

Outcomes - Noise Impact of Source by Scenario B

Testset Extent
Scale 1:7.500

0 0.1 0.2 0.3 0.4 0.5 km

SCENARIO A

Outcomes - Noise Impact at Receptor by Scenario A

Legend

INTENSITY (varying colour)
- Intensity factor 0.2 - 76 dB
- Intensity factor 0.4 - 82 dB
- Intensity factor 0.6 - 88 dB
- Intensity factor 0.8 - 94 dB
- Intensity factor 1.0 - 100 dB

TEMPORALITY (varying arrow)

Moment
- 03:00 AM
- 06:00 AM
- 09:00 AM
- 12:00 AM
- 03:00 PM
- 06:00 PM
- 09:00 PM
- 12:00 PM

Duration
- 2 minutes
- 4 minutes
- 6 minutes
- 8 minutes

Frequency
- 1 occurrence per 2 weeks
- 4 occurrences per 2 weeks

AFFECTED POPULATION (varying size)
- Population factor 0.2 - 2.7 people
- Population factor 0.4 - 5.4 people
- Population factor 0.6 - 8.2 people
- Population factor 0.8 - 10.9 people
- Population factor 1.0 - 13.6 people

NO IMPACT
- No Impact

Testset Extent
Scale 1:7.500

0 0.1 0.2 0.3 0.4 0.5 km

Legend

INTENSITY (varying colour)

Intensity factor 1.0 - over 70 dB

TEMPORALITY (varying arrow)

Moment

06:00 AM

09:00 AM

06:00 PM

09:00 PM

Duration

2 minutes

4 minutes

6 minutes

Frequency

1 occurrence per 2 weeks

4 occurrences per 2 weeks

AFFECTED POPULATION (varying size)

Population factor 0.2 - 351 people

Population factor 0.4 - 703 people

Population factor 0.6 - 1055 people

Population factor 0.8 - 1406 people

Population factor 1.0 - 1758 people

No Impact

Outcomes - Noise Impact of Source by Scenario A

Testset Extent
Scale 1:7.500

0 0.1 0.2 0.3 0.4 0.5 km

E.2 ODOUR IMPACT INDICATOR OUTCOMES

SCENARIO B

Outcomes - Odour Impact at Receptor by Scenario B

Municipality of Amsterdam
Scale 1:60.000

0 1 2 3 4 5 km

Legend

INTENSITY (varying colour)
- Intensity factor 0 to 20
- Intensity factor 20 to 40
- Intensity factor 40 to 60
- Intensity factor 60 to 80
- Intensity factor over 80

AFFECTED POPULATION (varying size)
- Population factor 50 - 680 people
- Population factor 100 - 1360 people
- Population factor 150 - 2040 people
- Population factor 200 - 2720 people
- Population factor 250 - 3400 people

Outcomes - Odour Impact at Receptor by Scenario B

Legend

INTENSITY (varying colour)
- Intensity factor 0.2 - 76 dB
- Intensity factor 0.4 - 82 dB
- Intensity factor 0.6 - 88 dB
- Intensity factor 0.8 - 94 dB
- Intensity factor 1.0 - 100 dB

TEMPORALITY (varying arrow)

Moment
- 03:00 AM
- 06:00 AM
- 09:00 AM
- 12:00 AM
- 03:00 PM
- 06:00 PM
- 09:00 PM
- 12:00 PM

Duration
- 2 minutes
- 4 minutes
- 6 minutes
- 8 minutes

Frequency
- 1 occurrence per 2 weeks
- 4 occurrences per 2 weeks

AFFECTED POPULATION (varying size)
- Population factor 0.2 - 2.7 people
- Population factor 0.4 - 5.4 people
- Population factor 0.6 - 8.2 people
- Population factor 0.8 - 10.9 people
- Population factor 1.0 - 13.6 people

NO IMPACT
- No Impact

Testset Extent
Scale 1:7.500

0 0.1 0.2 0.3 0.4 0.5 km

Outcomes - Odour Impact of Source by Scenario B

Municipality of Amsterdam
Scale 1:60.000

0 1 2 3 4 5 km

Legend

INTENSITY (varying colour)
- Intensity factor 1.0 - 1 container
- Intensity factor 2.0 - 2 containers
- Intensity factor 3.0 - 3 containers
- Intensity factor 4.0 - 4 containers
- Intensity factor over 4.0 - more than 4 containers

AFFECTED POPULATION (varying size)
- Population factor 0.5 - 31 people
- Population factor 1 - 18 people
- Population factor 1.5 - 92 people
- Population factor 2.0 - 122 people
- Population factor 2.5 - 153 people

Legend

INTENSITY (varying colour)

Intensity factor 1.0 - over 0.5 OUe

TEMPORALITY (varying arrow)

Moment

06:00 AM

09:00 AM

06:00 PM

09:00 PM

Duration

2 minutes

4 minutes

6 minutes

Frequency

1 occurrence per 2 weeks

4 occurrences per 2 weeks

AFFECTED POPULATION (varying size)

Population factor 0.2 - 12 people

Population factor 0.4 - 25 people

Population factor 0.6 - 37 people

Population factor 0.8 - 49 people

Population factor 1.0 - 61 people

No Impact

Outcomes - Odour Impact of Source by Scenario B

Testset Extent
Scale 1:7.500

0 0.1 0.2 0.3 0.4 0.5 km

SCENARIO A

Outcomes - Odour Impact at Receptor by Scenario A

Legend

INTENSITY (varying colour)
- Intensity factor 0.2 - 76 dB
- Intensity factor 0.4 - 82 dB
- Intensity factor 0.6 - 88 dB
- Intensity factor 0.8 - 94 dB
- Intensity factor 1.0 - 100 dB

TEMPORALITY (varying arrow)

Moment
- 03:00 AM
- 06:00 AM
- 09:00 AM
- 12:00 AM
- 03:00 PM
- 06:00 PM
- 09:00 PM
- 12:00 PM

Duration
- 2 minutes
- 4 minutes
- 6 minutes
- 8 minutes

Frequency
- 1 occurrence per 2 weeks
- 4 occurrences per 2 weeks

AFFECTED POPULATION (varying size)
- Population factor 0.2 - 2.7 people
- Population factor 0.4 - 5.4 people
- Population factor 0.6 - 8.2 people
- Population factor 0.8 - 10.9 people
- Population factor 1.0 - 13.6 people

NO IMPACT
- No Impact

Testset Extent
Scale 1:7.500

0 0.1 0.2 0.3 0.4 0.5 km

Legend

INTENSITY (varying colour)

Intensity factor 1.0 - over 0.5 OUe

TEMPORALITY (varying arrow)

Moment

06:00 AM

09:00 AM

06:00 PM

09:00 PM

Duration

2 minutes

4 minutes

6 minutes

Frequency

1 occurrence per 2 weeks

4 occurrences per 2 weeks

AFFECTED POPULATION (varying size)

Population factor 0.2 - 12 people

Population factor 0.4 - 25 people

Population factor 0.6 - 37 people

Population factor 0.8 - 49 people

Population factor 1.0 - 61 people

No Impact

Outcomes - Odour Impact of Source by Scenario A

Testset Extent
Scale 1:7.500

0 0.1 0.2 0.3 0.4 0.5 km

E.3 CONGESTION IMPACT INDICATOR OUTCOMES

SCENARIO B

Outcomes - Congestion Impact at Receptor by Scenario B

Municipality of Amsterdam

Scale 1:60.000

0 1 2 3 4 5 km

Legend

INTENSITY (varying colour)

- Intensity factor 0 to 10
- Intensity factor 10 to 20
- Intensity factor 20 to 30
- Intensity factor 30 to 40
- Intensity factor over 40

AFFECTED POPULATION (varying size)

- Population factor 5 - 90 people
- Population factor 10 - 180 people
- Population factor 15 - 270 people
- Population factor 20 - 360 people
- Population factor 25 - 450 people

Outcomes - Congestion Impact at Receptor by Scenario B

Municipality of Amsterdam

Scale 1:60.000

0 1 2 3 4 5 km

Legend

INTENSITY (varying colour)
- Intensity factor 0.2
- Intensity factor 0.4
- Intensity factor 0.6
- Intensity factor 0.8
- Intensity factor 1.0

TEMPORALITY (varying arrow)

Moment
- 03:00 AM
- 06:00 AM
- 09:00 AM
- 12:00 AM
- 03:00 PM
- 06:00 PM
- 09:00 PM
- 12:00 PM

Duration
- 2 minutes
- 4 minutes
- 6 minutes
- 8 minutes

Frequency
- 1 occurrence per 2 weeks
- 4 occurrences per 2 weeks

AFFECTED POPULATION (varying size)
- Population factor 0.2
- Population factor 0.4
- Population factor 0.6
- Population factor 0.8
- Population factor 1.0

NO IMPACT
- No Impact

Legend

INTENSITY (varying colour)

Intensity factor 0.2

Intensity factor 0.4

TEMPORALITY (varying arrow)

Moment

06:00 AM

09:00 AM

06:00 PM

09:00 PM

Duration

2 minutes

4 minutes

Frequency

1 occurrence per 2 weeks

4 occurrences per 2 weeks

AFFECTED POPULATION (varying size)

Population factor 0.2 - 4 people

Population factor 0.4 -7 people

Population factor 0.6 - 11 people

Population factor 0.8 - 14 people

Population factor 1.0 - 18 people

No Impact

Outcomes - Congestion Impact at Receptor by Scenario B

Testset Extent
Scale 1:7.500

0 0.1 0.2 0.3 0.4 0.5 km

Outcomes - Congestion Impact of Source by Scenario B

Municipality of Amsterdam

Scale 1:60.000

0 1 2 3 4 5 km

Legend

INTENSITY (varying colour)

- Intensity factor 1.0 - 1 container
- Intensity factor 2.0 - 2 containers
- Intensity factor 3.0 - 3 containers
- Intensity factor 4.0 - 4 containers
- Intensity factor over 4.0 - more than 4 containers

AFFECTED POPULATION (varying size)

- Population factor 0.5 - 9 people
- Population factor 1 - 18 people
- Population factor 1.5 - 27 people
- Population factor 2.0 - 36 people
- Population factor 2.5 - 45 people

Legend

INTENSITY (varying colour)

Intensity factor 0.2

Intensity factor 0.4

TEMPORALITY (varying arrow)

Moment

06:00 AM

09:00 AM

06:00 PM

09:00 PM

Duration

2 minutes

4 minutes

Frequency

1 occurrence per 2 weeks

4 occurrences per 2 weeks

AFFECTED POPULATION (varying size)

Population factor 0.2 - 4 people

Population factor 0.4 -7 people

Population factor 0.6 - 11 people

Population factor 0.8 - 14 people

Population factor 1.0 - 18 people

No Impact

Outcomes - Congestion Impact of Source by Scenario B

Testset Extent
Scale 1:7.500

0 0.1 0.2 0.3 0.4 0.5 km

SCENARIO A

Legend

INTENSITY (varying colour)

Intensity factor 0.2

Intensity factor 0.4

TEMPORALITY (varying arrow)

Moment

06:00 AM

09:00 AM

06:00 PM

09:00 PM

Duration

2 minutes

4 minutes

Frequency

1 occurrence per 2 weeks

4 occurrences per 2 weeks

AFFECTED POPULATION (varying size)

Population factor 0.2 - 4 people

Population factor 0.4 -7 people

Population factor 0.6 - 11 people

Population factor 0.8 - 14 people

Population factor 1.0 - 18 people

No Impact

Outcomes - Congestion Impact at Receptor by Scenario A

Testset Extent

Scale 1:7.500

0 0.1 0.2 0.3 0.4 0.5 km

Legend

INTENSITY (varying colour)

Intensity factor 0.2

Intensity factor 0.4

TEMPORALITY (varying arrow)

Moment

06:00 AM

09:00 AM

06:00 PM

09:00 PM

Duration

2 minutes

4 minutes

Frequency

1 occurrence per 2 weeks

4 occurrences per 2 weeks

AFFECTED POPULATION (varying size)

Population factor 0.2 - 4 people

Population factor 0.4 -7 people

Population factor 0.6 - 11 people

Population factor 0.8 - 14 people

Population factor 1.0 - 18 people

No Impact

Outcomes - Congestion Impact of Source by Scenario A

Testset Extent

Scale 1:7.500

0 0.1 0.2 0.3 0.4 0.5 km

E.4 CO_2 IMPACT INDICATOR OUTCOMES

SCENARIO B

Outcomes - CO2 Emission of Source by Scenario B

Municipality of Amsterdam
Scale 1:60.000

0 1 2 3 4 5 km

Legend

- Total mass:
- up to 1 kg
- 1 to 2 kg
- 2 to 3 kg
- 3 to 4 kg
- over 4 kg

Outcomes - CO2 Impact of Source by Scenario B

Testset Extent
Scale 1:7.500

0 0.1 0.2 0.3 0.4 0.5 km

Legend

INTENSITY (varying colour)

- Intensity factor 0.2 - 0.6 kg/km
- Intensity factor 0.4 - 1.2 kg/km
- Intensity factor 0.6 - 1.8 kg/km
- Intensity factor 0.8 - 2.4 kg/km
- Intensity factor 1 - 3 kg/km

SCENARIO A

Outcomes - CO2 Impact of Source by Scenario A

Legend

INTENSITY (varying colour)

- Intensity factor 0.2 - 0.6 kg/km
- Intensity factor 0.4 - 1.2 kg/km
- Intensity factor 0.6 - 1.8 kg/km
- Intensity factor 0.8 - 2.4 kg/km
- Intensity factor 1 - 3 kg/km

Testset Extent
Scale 1:7.500

0 0.1 0.2 0.3 0.4 0.5 km

E.5 WASTE COLLECTION IMPACT INDICATOR OUTCOMES

SCENARIO B

Outcomes - Waste Collection at Receptor by Scenario B

Municipality of Amsterdam

Scale 1:60.000

0 1 2 3 4 5 km

Legend

- Total Waste Mass:
- up to 500 kg
- 500 to 1000 kg
- 1000 to 1500 kg
- 1500 to 2000 kg
- over 2000 kg

Outcomes - Waste Collection Impact at Receptor by Scenario B

Testset Extent
Scale 1:7.500

0 0.1 0.2 0.3 0.4 0.5 km

Legend

INTENSITY (varying colour)

- Intensity factor 0.2 - 13 kg
- Intensity factor 0.4 - 26 kg
- Intensity factor 0.6 - 39 kg
- Intensity factor 0.8 - 52 kg
- Intenstiy factor 1.0 - 65 kg
- No Impact

Outcomes - Waste Collection of Source by Scenario B

Municipality of Amsterdam

Scale 1:60.000

0 1 2 3 4 5 km

Legend

- Total Waste Mass:
- up to 500 kg
- 500 to 1000 kg
- 1000 to 1500 kg
- 1500 to 2000 kg
- over 2000 kg

Outcomes - Waste Collection Impact of Source by Scenario B

Testset Extent
Scale 1:7.500

0 0.1 0.2 0.3 0.4 0.5 km

Legend

INTENSITY (varying colour)

- Intensity factor 0.2 - 1132 kg
- Intensity factor 0.4 - 1491 kg
- Intensity factor 0.6 - 1849 kg
- Intensity factor 0.8 - 2207 kg
- Intensity factor 1 - 2566 kg

SCENARIO A

Outcomes - Waste Collection Impact at Receptor by Scenario A

Testset Extent

Scale 1:7.500

0 0.1 0.2 0.3 0.4 0.5 km

Legend

INTENSITY (varying colour)

- Intensity factor 0.2 - 13 kg
- Intensity factor 0.4 - 26 kg
- Intensity factor 0.6 - 39 kg
- Intensity factor 0.8 - 52 kg
- Intenstiy factor 1.0 - 65 kg
- No Impact

Outcomes - Waste Collection Impact of Source by Scenario A

Testset Extent

Scale 1:7.500

0 0.1 0.2 0.3 0.4 0.5 km

Legend

INTENSITY (varying colour)

- Intensity factor 0.2 - 1132 kg
- Intensity factor 0.4 - 1491 kg
- Intensity factor 0.6 - 1849 kg
- Intensity factor 0.8 - 2207 kg
- Intensity factor 1 - 2566 kg

COLOPHON

This document was typeset using LaTeX. The document layout was generated using the `arsclassica` package by Lorenzo Pantieri, which is an adaption of the original `classicthesis` package from André Miede.