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Masscycle – A Tool for Circular Project Planning of Sustainable Mass Management

Master's Thesis in the Master's Programme Infrastructure and Environmental
Engineering

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CHALMERS UNIVERSITY OF TECHNOLOGY
Gothenburg, Sweden 2024
www.chalmers.se

MASTER'S THESIS ACEX60

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Examensarbete ACEX60

Institutionen för arkitektur och samhällsbyggnadsteknik
Chalmers tekniska högskola, 2024

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ABSTRACT

With the ongoing infrastructure projects in today's society, large quantities of excavated soil material emerge that need to be handled. Road infrastructure projects are a part of the major development, causing an increase of excavated rock and soil masses as roads are constructed. Due to the technical and/or environmental properties of the material it is not always utilized and instead ends up at disposal sites. Through properly executed mass management these masses can be viewed as resources instead of waste. The overall aim of this thesis is to develop a tool that can be used for planning of mass management during the pre-construction phase, within road infrastructure projects at the Swedish Transport Administration. To reach the aim, a method consisting of a literature review, development of a tool and two case studies was carried out. In the literature review, existing digital tools and methods for mass management were studied and key performance indicators regarding the planning of mass management were identified. The tool, Masscycle, was developed in Excel and consists of different sheets that combined, help fulfil demands in the requirements document set by the Swedish Transport Administration. Masscycle combines the input data from users to automatically create visualizations and provide results about the studied road infrastructure project. In addition, key performance indicators are calculated as measures of the level of circularity of the project. Masscycle was tested on two road infrastructure projects and proved to be useful in the planning for sustainable and circular mass management. Implementation of Masscycle at the Swedish Transport Administration should be carried out to ensure a uniform way of reporting mass management.

Key words: mass handling, excavated soils, earth works, key performance indicator, construction, recycle, reuse, Masscycle, Swedish Transport Administration, aggregates

Masscycle – Ett verktyg för cirkulär projektering av hållbar masshantering

Examensarbete inom mastersprogrammet infrastruktur och miljöteknik

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SAMMANFATTNING

Till följd av de pågående infrastrukturprojekten i dagens samhälle uppstår stora mängder schaktmassor som behöver hanteras. Vägprojekt är en del av utvecklingen, och orsakar en ökning av schaktade berg- och jordmassor när vägar byggs. Till följd av tekniska och miljömässiga egenskaper hos massorna kan de inte alltid nyttiggöras och hamnar istället på deponi. Genom ordentligt utförd masshantering kan dessa massor ses som en resurs istället för avfall. Det övergripande syftet med detta arbete är att utveckla ett verktyg som kan användas för planering av masshantering, under projekteringsfasen, inom vägprojekt på Trafikverket. För att uppfylla syftet genomfördes en metod som bestod av en litteraturstudie, utveckling av ett verktyg och två fallstudier. I litteraturstudien studerades befintliga digitala verktyg och metoder och nyckeltal för planering av masshantering. Verktuget, Masscycle, utvecklades i Excel och består utav olika blad som tillsammans bidrar till att uppfylla Trafikverkets kravtext. Masscycle kombinerar indata från användaren för att automatiskt skapa visualiseringar samt ge resultat om det studerade vägprojektet. Dessutom beräknas nyckeltal som ett mått för projektets cirkularitet. Masscycle testades på två vägprojekt och visade sig vara användbar i planeringen för hållbar och cirkulär masshantering. Implementering av Masscycle på Trafikverket bör genomföras för att säkerställa ett enhetligt sätt att rapportera masshantering.

Nyckelord: masshantering, schaktmassor, jordmassor, bergmassor, nyckeltal, verktyg, återvinning, projektering, planering, Trafikverket

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Preface

This thesis was written within the Master's Programme Infrastructure and Environmental Engineering at the department of Architecture and Civil Engineering, Chalmers University of Technology and was conducted during the autumn term of 2023 and spring term of 2024. We are sincerely grateful for the support and constructive feedback we have received from our supervisor Jenny Norrman and our examiner Lars Rosén. We would also like to thank our supervisor at the Swedish Transport Administration, Joakim Claesson, for all of his ideas and the time he spent teaching us about mass management. Furthermore, we are thankful for Jonas Edelberg who believed in Masscycle and introduced a pilot project for the tool. Finally, we would like to thank the involved employees at the Swedish Transport Administration for contributing with inputs and ideas for the development of Masscycle.

Göteborg May 2024

Olivia Jansson & Karolina Olsson

Glossary

Ball mill value <i>Kulkvarnsvärde</i>	The proportion of a sample (in percentage by weight) which after treatment in a ball mill passes through a 2 mm sieve.
Civil engineering works <i>Anläggning</i>	A nonbuilding structure such as a bridge, tunnel, road or railway.
Emerged masses <i>Uppkomna massor</i>	Emerged masses represent the soil and rock material that is excavated.
Key performance indicator (KPI) <i>Nyckeltal</i>	Key performance indicators refer to a quantifiable measure of performance over time for a specific objective.
Needed masses <i>Behov av massor</i>	Needed masses represent the demand for soil and rock material during construction.
Pre-construction phase <i>Projekteringsfasen</i>	The phase in a construction process where detailed project planning and design is carried out.
Regulating authority <i>Tillsynsmyndighet</i>	A regulating authority is responsible for ensuring that a subordinate agency complies with the requirements for a specific operation.
Requirements document <i>Kravtext</i>	Document with demands set by the Swedish Transport Administration on their consultants. Contains demands regarding the reporting of the planning of mass management. This document is originally called Requirements - Deliveries in consultant commissions (in Swedish: <i>Krav - Leveranser i konsultuppdrag</i>), but is referred to as requirements document in this thesis.
Surplus masses <i>Överskottsmassor</i>	Surplus masses represent the excess soil and rock material that <i>emerge</i> during excavation.
Target for KPI <i>Målvärde</i>	The value of a <i>key performance indicator</i> that should be strived for.
Utilized masses <i>Nyttiggjorda massor</i>	Utilized masses represent the soil and rock material that <i>emerge</i> during excavation and is used within the project.

1 Introduction

1.1 Background

In 2019, more than 100 billion tonnes of natural resources were utilized globally, with minerals and ores constituting half of this consumption (Larsson & Gammelsæter, 2023). Construction and infrastructure accounted for the near majority, almost 40% of these resources. The current circularity rate in Europe is 7% and if it were to increase to 20%, 6 billion Euro and 546 million tonnes of rock materials could be saved annually (Larsson & Gammelsæter, 2023). In the last twenty years, there has been a notable increase in studies that examine the environmental and economic consequences of the construction and demolition industries, with a specific emphasis on how waste materials are generated and handled (Ghisellini et al., 2018). Among several other sectors, circular economy has great potential in the construction industry, as waste from construction and demolition stands for over a third of all of the waste generated within the EU (European Commission, 2021).

The Waste Frame Directive, defines concepts related to waste management and has established a waste hierarchy for how waste management should be carried out within the European Union (European Commission, 2023). The directive includes basic waste management principles. Firstly, waste should be managed without causing harm to the environment or human health and not risk water, air, soil, animals or plants. Secondly, it should not cause a discomfort through odours or noise. Lastly, waste should be managed in a way that does not affect the countryside or places of special interest in a negative way. The waste hierarchy defines the order in which waste should be managed. The preferences for managing waste from most to least preferable are: prevention, preparing for re-use, recycling, recovery and disposal.

The many construction projects going on today, such as exploitation, expansion and renewal of infrastructure lead to a large portion of excavated masses that need to be handled. Due to the constraint of limited resources, it is crucial to reduce landfilling and increase material recycling. Results from Ghissellini et al. (2018) suggest that reusing and recycling construction and demolition waste during a buildings' end-of-life stage along with the production of recycled products give rise to both economic and environmental benefits. Furthermore, it is also pointed out that how large these benefits are, strongly depend on site-specific factors.

Construction and demolition waste includes several categories of material, where soil is considered to be one of them (Manjunath & Umrigar, 2017). During construction and demolition of infrastructure systems, such as roads and railways, there is an emergence of soil (Larsson & Gammelsæter, 2023). Soil masses are finite resources, with a social, economic and environmental value. The challenges associated with using and recycling excavated soil are related to the availability of raw materials and the lack of reported data (Larsson & Gammelsæter, 2023). In Nordic countries there is an abundance of raw materials, such as rock and this availability decreases the need for recycling. Furthermore, there is a lack of statistics for follow up related to the quantities of excavated soil masses. This absence of data indicates that the soil material is not seen as a resource.

In 2015, the United Nations came to a consensus on the 2030 Agenda for Sustainable Development, which encompasses 17 interconnected Sustainable Development Goals (Independent Group of Scientists appointed by the Secretary-General, 2023). This collective agreement serves as a global initiative to eradicate poverty and take care of the planet. The goals, 9: Industry innovation and infrastructure, 11: Sustainable cities and communities, 12: Responsible consumption and production, and 13: Climate action, are directly related to mass management and address societal, ethical and ecological aspects. They indicate that mass management is essential on both a regional level and global level.

The Swedish Transport Administration, desires to enhance mass management practices both within their organization and among their contractors in order to work with the subject in a circular and sustainable manner (Brolenius, 2022). The problem that the Swedish Transport Administration is dealing with today is that masses in construction projects are often contaminated and need to meet certain technical and environmental standards in order to be reused for other purposes (Andersson-Sköld et al., 2022). For various reasons, reuse of masses is not carried out in many projects, and instead the masses end up in landfills. Through well executed project planning, circular and sustainable mass management can be carried out. Andersson-Sköld et al. (2022) states that there is a need for key performance indicators, KPIs, in order to evaluate different strategies for management of excavated masses. One reason for this is that the KPIs should form the basis for demanding that recycling strategies be proposed in procurements. In addition, KPIs could simplify the comparison of these proposed strategies as well as provide incentives for increased recycling.

1.2 Aim and objectives

The overall aim of this thesis is to develop a practical tool that can contribute to enhanced mass management and circular project planning in road infrastructure projects at the Swedish Transport Administration. To reach the overall aim, a literature review is carried out to support the design of the tool, followed by its development, testing and evaluation. The literature review is carried out to

- identify existing digital tools and methods developed to improve mass management and study how these are currently being applied
- identify KPIs and targets for KPIs that can be used to measure and report the level of sustainability or circularity of mass management in a project.

Further, the tool should

- fulfil the Swedish Transport Administration's requirements document on consultants for the PM Mass Management i.e., report quantities and create visualizations of emerged, needed, utilized and surplus masses
- present KPIs and targets for KPIs relating to the requirements by the Swedish Transport Administration
- be developed in Excel for easy use and accessibility.

Finally, to test the applicability and refine the tool it will be

- evaluated using existing road infrastructure project from the Swedish Transport Administration

- used to evaluate potential uncertainties regarding mass management in the projects by creating scenarios.

1.3 Limitations

The tool will be designed for project use, thereby functioning on a project scale. It will not provide results regarding effects on a regional or societal scale. This limitation is set due to the Swedish Transport Administration's requirements document being designed for individual projects. Furthermore, a project-based tool is seen as necessary before creating a tool on a regional or societal scale.

The tool will not be created to fulfill all of the demands in the requirements document, only those that concern quantities, tables and visualizations. For the included parts of the requirements document, see Appendix A.

Mass management in infrastructure projects other than road projects will not be taken into account when creating the tool. Regarding mass management, this report will only cover soil and rock masses. Other demolition waste such as asphalt, concrete and plastic will not be included.

The only program that will be used to create and use the tool will be Excel. The process of submitting the Excel tool to create an official document template within the Swedish Transport Administration will not be done within the scope of this project. Because of this, efforts will not be made to make sure that the tool fulfills all of Swedish Transport Administration's requirements for a document template.

1.4 Layout of the report

This thesis is divided into six chapters: Introduction, Theory, Methodology, Results, Discussion, and Conclusions and Recommendations. In the introduction a background on mass management is described as well as the aim, objectives and limitations of the thesis.

The second chapter outlines a definition for sustainable and circular mass management, a description of the Swedish approach to mass management, and an analysis of mass management from an international perspective.

Chapter three describes the methodology used to acquire results from the literature review and the methodology used for the development of the tool, as well as how the case studies were performed.

Chapter four presents the results from the literature review, the results from the development of the tool, as well as the final design. This chapter also entails the results from the case studies. During the development of the tool, it was named Masscycle. This name will be used throughout this report to refer to the tool created for this thesis work.

Chapter five discusses the implementation of KPIs into Masscycle, analyses the results of the case studies and explores the effects of subjectivity connected to inputs in Masscycle. Further, this chapter includes a comparison between the tool and the

Swedish Transport Administration's requirements document, as well as a discussion on benefits and drawbacks of an Excel-based tool compared to a web-based tool. Lastly, this chapter describes the future of Masscycle, in terms of its implementation at the Swedish Transport Administration and its impact on project planning.

Chapter six presents the main conclusions from this thesis as well as recommendations for further work.

In this thesis there are three appendices. In Appendix A the relevant components of the requirements document for the development of Masscycle are presented. Appendix B describes in detail the problems and solutions that arose during the designing and programming of Masscycle. Appendix C consists of the instructions for Masscycle. Appendix D presents additional visualizations for the case studies.

2 Theory

In an era characterized by unprecedented environmental challenges, growing awareness of infinite resources and shifts in society, the concept of sustainability grows more and more important. A commonly acknowledged definition of the term sustainable development was presented in the Brundtland report from 1987: “Sustainable development is development that meets the needs of the present without compromising the ability of future generations to meet their own needs” (MacNeill, 1987).

According to Bozeman and Theis (2023), sustainability can be divided into three fundamental components: societal-, economical- and environmental sustainability. Without one of these components, sustainability cannot be achieved effectively. Among other subjects, a sustainable society includes the health, wellness and needs of individuals and groups. The economical component of sustainability refers to the effective allocation and utilization of resources. Environmental sustainability involves being cautious about and preserving Earth’s resources.

Circular economy is one example of a concept that fits the idea of sustainable development. The concept of circular economy involves economic models characterized by a strong emphasis on recycling and effective resource utilization (Nationalencyklopedin, 2023). The key aspect of circular economy is the utilization of waste materials from production and consumption as inputs in other production processes. Redirecting end-of-life products from final disposal at landfills to a production phase is the fundamental difference between the classical linear economy and the modern circular economy (Nikolaou & Tsagarakis, 2021).

Circular economy can be implemented and analyzed at different levels: micro, meso, and macro (Nikolaou & Tsagarakis, 2021). At a micro-level, circular economy is introduced within one organization and focuses on integrating the circular view into production and operation. The meso-level includes circular economy across several companies through collaboration. At this level the waste from one company can be seen as a raw material for another. The macro-level stretches the included parties in the circular economy to a whole city, region or even nation. It includes broader policies, specialized tools, and comprehensive strategies.

2.1 Sustainable and circular mass management

According to the Swedish Environmental Protection Agency (in Swedish: Naturvårdsverket), sustainable mass management is defined as a system wherein appropriate masses from an environmental and human health perspective are circulated in a manner relating to the purpose of the use (Naturvårdsverket, 2022). The evaluation of suitability of the masses is based on the potential risks they may pose to human health and the environment both in the short and long term. Furthermore, the Swedish Environmental Protection Agency states that circular and resource efficient mass management involves reducing the extraction of geological natural resources, decreasing transportation and greenhouse gas emissions, along with providing favorable conditions for a safe and healthy living environment unthreatened by the presence of hazardous materials in the environment.

In an interview conducted by Andersson-Sköld et al. (2022) with different parties within the infrastructure sector, respondents described circular mass management as a cycle, where the aim is to recycle masses instead of landfilling them or acquiring them from quarries. It was also stated that masses should be seen as a resource that can be used directly, or be treated and then become a product to be used for suitable applications. Another aspect that was seen as important was to use the masses in a manner that corresponds to a high level in the value chain.

The Swedish Environmental Protection Agency has evaluated mass management in Sweden and several challenges with the current approach were identified (Naturvårdsverket, 2022). The challenges depend on a number of factors, which cause ineffective resource use. One factor is the difficulty in defining masses as waste or as resources, since it affects which regulation is applicable. A second factor is an ineffective matching of emerging masses with demand of masses, which makes it difficult to find appropriate allocation of the masses. A third factor is defined as deficiencies in planning and coordination, which is partly caused by a lack of useful tools for planning of mass management. The last factor mentioned is the complex legislation together with deficiencies in guidance.

Regarding the term “waste”, the Swedish Environmental Protection Agency’s assessment suggests that several adjustments are required within the existing legal framework to effectively address the numerous challenges encountered in achieving sustainable mass management (Naturvårdsverket, 2022). They assert the need for changes in waste related regulations and emphasize the necessity for placing additional demands on materials categorized as products (materials where there is not a disposal interest and thus not waste). Therefore, they suggest an implementation of mandatory assessments for the handling of product materials.

A well-functioning supply and demand system would better enable a sustainable mass management. The Swedish Environmental Protection Agency highlights two main reasons behind the difficulties in matching supply and demand of excavated masses (Naturvårdsverket, 2022). Firstly, the lack of knowledge and information regarding the content and characteristics of the masses makes it difficult to create a supply of a certain material. Secondly, in some cases it is economically beneficial to dispose of the masses rather than reusing them.

Planning and coordination of the emergence and demand of masses in time and space is important in order to achieve a sustainable mass management (Naturvårdsverket, 2022). In Sweden today, there is not always a need for all types of masses, at the exact time that they emerge. Therefore, there is a need for more locations that can store masses over a longer period of time. In addition to more storage locations, the Swedish Environmental Protection Agency also suggests increasing the allowed time for masses to be stored before being recycled, as the current allowed time is three years.

The prerequisites of the regulating authorities are also affected by the complicated legal framework regarding mass management (Naturvårdsverket, 2022). Since the framework can be complicated to interpret it is difficult for businesses to provide documentation that the regulating authority can review and approve. Furthermore, the Swedish Environmental Protection Agency suggests involving the regulating authorities earlier in projects, and thereby improving the collaboration between

regulating authorities and businesses as well as improving the regulating authorities' prerequisites.

In the Australian capital region several barriers for recycling and reuse of construction and demolition waste, including excavated soil, have been identified (Zou et al., 2015):

- limited knowledge of recyclable materials and available recycling options
- contamination of recyclables caused by inadequate separation or limited space for separation
- alternatives to recycling being less costly
- recycling not being promoted by government policies
- a lack of recycling facilities.

Some strategies to reduce the effect of the barriers were also identified (Zou et al., 2015):

- governments providing temporary parcels of land to store waste material
- developing an application that can be used to sell and buy soil
- education to encourage the industry to see waste as a potential resource.

Hale et al. (2021) have identified barriers to recycling excavated soils in the construction industry. These barriers are categorized in four groups, regulatory barriers, organizational barriers, logistical and economical barriers and material quality barriers. Regulatory barriers consist of the existing or lack of regulations from authorities and other regulatory bodies. The organizational barriers are related to the project planning process. The logistical and economic barriers are connected to the fact that supply and demand usually do not match. The material quality barrier are the unclear guidelines for test and risk assessment procedures.

2.2 The Swedish approach to mass management

The Swedish Environmental Code, Miljöbalk (SFS 1998:808), aims to promote a sustainable development, which secures a healthy environment for current and future generations. According to the Swedish Environmental Code, the definition of waste is: all objects or material that the project owner wants to dispose of or has to dispose of. Based on the definition of waste, the Swedish Environmental Protection Agency has provided guidance on how it can be applied to masses (Naturvårdsverket, 2023). Masses, such as soil, rock and asphalt, that emerge from different processes have a potential to be used in construction projects. If excavated soil and rock masses are recycled in road infrastructure projects, they need to be used in the sub-base (Magnusson et al., 2015).

According to the Swedish Environmental Protection Agency, masses are not waste if there exists a guaranteed market and the masses are appropriate from both an environmental and health point of view (Naturvårdsverket, 2023). In order to prove that there exists a guaranteed market, there needs to be a demand for masses on a foreseeable market that can be determined in time. The masses also need to meet certain technical and environmental requirements for the specific market. To have a foreseeable market the operator should be able to verify the demand, for instance by referring to statements in a regional mass management plan. The masses are classified as waste if: 1) there is

no market for the emerging masses, 2) the only market is too far into the future (unspecified timeframe), or 3) the masses are not appropriate from an environmental and health point of view. When the masses have been determined to be waste, they can either go through material recycling or they have to be disposed of, e.g., by landfilling (Naturvårdsverket, 2023). Material recycling can be done in two ways. One approach is recycling in construction work. This is possible if the masses, containing pollutants, are suitable for the conditions on the specific site. The second method is if the masses are in need of remediation before use. When they have been remediated, they cease to be waste.

The Swedish Transport Administration base their method of working with mass management from directions by the Swedish Environmental Protection Agency (Naturvårdsverket, n.d). The demands that the Swedish Transport Administration has on its consultants in the requirements document (see Appendix A) should result in a report called PM Mass Management (Trafikverket, 2022b).

2.2.1 Classification systems

The Swedish Environmental Protection Agency has developed a model to establish recommended reference levels for remediation of contaminated land, taking into account typical conditions found at polluted sites across Sweden (Naturvårdsverket, 2009). These guidelines are designed to protect both human health and the environment at the majority of the identified contaminated sites. In cases where these generic values do not accurately reflect the conditions of a particular site, site specific guideline values can be employed. The Swedish generic guideline values have been set for two distinct land use categories: “sensitive land use” (KM –“känslig markanvändning”) and “less sensitive land use” (MKM –“mindre känslig markanvändning”) (Naturvårdsverket, 2009). The primary aim of these guideline values is to ensure the protection of individuals who visit or reside on the site.

Furthermore, the Swedish Environmental Protection Agency has recommended a level for when the risk of recycling waste is “less than slight” (MRR –“mindre än ringa risk”) (Naturvårdsverket, 2010). At this level the Swedish Environmental Protection Agency suggests that the waste does not need to be reported to the regulating authority. There are two exceptions from this recommendation: 1) if there may be other contaminants that can affect the risk or 2) if the use of the waste takes place at a site where special considerations need to be taken into account.

Another way to classify masses is through their leachability properties. Excavated masses can be categorized as either inert, non-hazardous or hazardous (Naturvårdsverket, 2007). If the masses are to be disposed of at landfills, the degree of leachability has to be determined, as landfills are categorized after which type of masses they accept i.e., inert, non-hazardous or hazardous waste. There are specific threshold values for different substances, that decide if the material is inert, non-hazardous or hazardous. To define masses as inert waste the following must be fulfilled:

- It does not undergo any biological, chemical or physical changes.
- It is nonbiodegradable.
- It does not interact with other materials in a way that potentially can cause harm to the environment or human health.

- It has negligible total leachability and total contaminant content.
- The ecotoxicity of the leachate does not harm the quality of surface or groundwater.

The Swedish Transport Administration has developed requirements for classifying excavated masses (Rossander, 2022a). The purpose of these requirements is to ensure a consistent and sustainable approach to managing masses emerged in infrastructure projects, with a focus on high levels of utilization. The aim of the document is to contribute to a systematic approach to sampling, analysis, and evaluation of masses in projects undertaken by the Swedish Transport Administration. This includes enabling cooperative sampling within specialized areas like geotechnics and rock engineering. The goal is to establish a uniform methodology for classifying masses, applicable from the initial planning stages to the finished civil engineering works and their subsequent maintenance. To use emerged masses in an area, it is necessary to not only consider the contamination level of the masses, but also the areas prerequisites (Rossander, 2022b). Therefore, classification of emerged masses can be done according to the benchmarks of land area, L1, L2, S1 or S2, i.e., classifying which land area emerged masses are suitable for. It is also necessary to classify the area with a need according to the categories L1, L2, S1 or S2, in order to decide if the emerged masses can be utilized on the designated area.

In Table 2.1 the land areas are presented together with their definition and examples. L details that the area is a small area, less than 500 m² (Rossander, 2022b). S specifies that the area is a large area, more than 500 m². The size of the area is specified according to the associated risk of contaminants spreading through groundwater and/or surface water. The size directly influences the quantity of contaminants in the area and their dilution. 1 and 2 are descriptions for the area's top layer, where 1 is associated with a permeable surface and 2 signifies an impermeable surface, which in turn indicates if contaminants will be able to infiltrate the top layer (Rossander, 2022b). For the land areas where infiltration is possible, L1 and S1, some benchmarks for protection of land environment is put in place as well, to ensure a liveable environment for organisms and plants. Another parameter included in land area is human exposure time, which describes the assessed probability of humans being exposed to the land area (Rossander, 2022b). The parameter includes the exposure, in terms of long-term effects, short-term exposure and acute toxicity, of the events: ingesting soil, skin contact with soil and inhalation of dust and vapour.

Table 2.1 Description and examples of land area L1, L2, S1, and S2 (Rossander, 2022a). Translated by the authors.

Land area		Top layer	Human exposure time	Example of land use or activity within the land area
L1	Small area, <500 m ²	Permeable surface	Limited exposure time, around 2 hours per day for children and adults, or around 30 days per year for children and adults.	The permeable part of a roundabout, road embankment, road area (inner and outer slopes, as well as any shoulder strip 0.5-2m outside

				the crest edge), smaller excavations, foundation replacements, sewerage, or smaller permeable surfaces.
L2	Small area, <500 m ²	Impermeable surface, no protection of land environment	Limited exposure time, around 2 hours per day for children and adults, or around 30 days per year for children and adults. Low exposure to masses due to the impermeable surface.	Bus stop, passing pocket, or another smaller impermeable surface.
S1	Large area, >500 m ²	Permeable surface	Moderate exposure time, around 3 hours per day for children and adults or around 45 days per year for children and adults.	Railway, marshalling yard, embankments, embankment widening, service roads, gravel roads, road area (inner and outer slopes, as well as any shoulder strip 0.5-2m outside the crest edge), noise barriers, or other larger permeable surfaces.
S2	Large area, >500 m ²	Impermeable surface, no protection of land environment	Limited exposure time, around 2 hours per day for children and adults, or around 30 days per year for children and adults. Low exposure to masses due to the impermeable surface.	Road, pedestrian and bicycle path, platform, or another larger impermeable surface.

The legal framework, AMA Anläggning 23, is used in civil engineering works and contains requirements for methods, technologies and materials (Svensk Byggtjänst, 2023). The definition of AMA is “General material and work specifications”. In AMA Anläggning 23 there are two tables, AMA CE/1 and AMA CE/2 presented in Table 2.2, which contain lists of material types. In table AMA CE/1, the material types are a

classification of fill material of soil and rock for construction. It is based on the percentage of fine soil, clay and organic soil in the material. The material types are categorized as 1, 2, 3A, 3B, 4A, 4B, 5A, 5B, 6A and 6B. In table AMA CE/2, the material types are a classification of fill material for vegetation surfaces. It is based on the percentage of material under a certain size. In AMA CE/2, the material types are categorized as 11, 12a, 12b, 13a, 13b, 14a, 14b and 15. AMA Anläggning 23 also contains codes for construction within civil engineering works. These codes contain instructions for how a certain task is supposed to be executed. In many of these construction codes, there are specified material types that describe what kind of material that is allowed for that certain construction work.

Table 2.2 Material types and descriptions from the tables AMA CE/1 and AMA CE/2, together with examples of construction codes (Svensk Byggtjänst, 2023). Translated by the authors.

Material type	Name of soil and rock material	Example	Example of construction code & description
1	Rock type A	Mica-poor granite or gneiss and other hard and strong rocks such as quartzite, dolerite, porphyry and leptite	CEB.111 Filling with blasted rock for roads, plans, etc. CEB.53 Filling against foundation
	Rock type B	Mica-rich granite or gneiss and other rocks with moderate strength and poor wear resistance	
2	Boulder and stony soils Coarse-grained soils	Boulder, rock, gravel, sand, sandy gravel, gravely sand, gravel till, sand till	CEB.212 Filling with aggregate for building foundations
3A	Rock type C	Rocks with high mica levels, clay shale, some coarse-grained granites and some porous sedimentary rocks, very strong transformed rocks	CEB.111 Filling with blasted rock for roads, plans, etc. CEB.82 Backfill against light materials
3B	Mixed-grain soils	Clayey or silty sand, clayey or silty gravel, clayey or silty sandy till, clayey or silty gravel till, clayey or silty till	CEB.82 Backfill against light materials CEC.3111 Filling around water and sewer lines

	Rock type D	Rocks with high mica levels, clay shale, chalk limestone, clay-converted rock, not classified rock material	
4A	Mixed-grain soils	Rocks with high mica levels, clay shale, chalk limestone, clay-converted rock, not classified rock material	CEB.214 Filling with mixed or fine-grained soil for building foundations CEC.3111 Filling around water and sewer lines
4B	Fine-grained soils	Clay, clay till	CEB.214 Filling with mixed or fine-grained soil for building foundations CEC.3111 Filling around water and sewer lines
5A	Fine-grained soils	Silt, muddy silt, silty clay, silt till, silty clay till	CEB.322 Filling with mixed and fine-grained soil for railways
5B	Mineral soils with organic content	Muddy clay, muddy silt	CEB.11222 Category B filling with mixed and fine-grained soil for road plan etc.
6A	Organic, mineral soils	Clayey mud, silty mud, sandy humus soil	There are no construction codes for this material type
6B	Organic soils	Mud, peat, humus soil	There are no construction codes for this material type
11	Rock material	Blasted rock, gravel	CEB.121 Filling with blasted rock for vegetation surface
12a	Stone till, coarse and mixed grained till Coarse soil Particle size > 2 mm	Clay-free or clay-poor gravelly soil, sandy gravel till	CEB.122 Filling with soil material for vegetation surface
12b	Stone till, coarse and mixed grained till	Clay-free or low-clay sandy soil, gravelly sandy till	CEB.122 Filling with soil material for vegetation surface

	Coarse soil Particle size < 2 mm		
13a	Fine and mixed grain till Fine soil Particle size > 0.02 mm	Gravelly or sandy silt soils, loamy gravel, sandy or sandy soils, silty or loamy sand till	CEB.122 Filling with soil material for vegetation surface
13b	Fine and mixed grain till Fine soil Particle size < 0.02 mm	Clayey silt soil, light clay, clayey silt till	CEB.122 Filling with soil material for vegetation surface
14a	Fine grain till, fine soil with dry crust character, particle size > 0.002 mm	Medium clay, clay till	CEB.122 Filling with soil material for vegetation surface
14b	Fine grain till, fine soil with dry crust character, particle size < 0.002 mm	Stiff clay and very stiff clay, clay till	CEB.122 Filling with soil material for vegetation surface
15	Fine soil without dry crust character	Medium clay, stiff clay and very stiff clay	There are no construction codes for this material type

2.2.2 Methods for treating excavated masses

There are several methods that can be used to treat excavated masses thus decreasing their contamination level. Dry sieving or conventional sieving is a method for recycling masses (Mácsik et al., 2020). It is also possible to recycle soil and rock masses using wet sieving, which is done through several steps of separating and sorting (Swerock, 2020). A more effective means of reducing soil pollutants is through soil washing (SGF-Åtgärdsportalen, 2023). In this approach several treatment steps are included, where dry and wet sieving is the first step. Depending on the type of pollutants and the contamination level, different processes are used. For organic particle-bound, silt and clay particles, pollutants are separated from the larger uncontaminated gravel and stone material through the use of flocculation. The polluted silt and clay particles are then removed from the water by flotation and sedimentation. The treatment capability of an average soil washing facility is around 5-50 tonnes/hour.

2.3 Mass management from an international perspective

The reuse of excavated masses within construction projects is an emerging topic worldwide. In the following chapters, a description of how mass management is carried out will be presented for the countries: Australia, Finland, France, Japan and the United Kingdom. These countries were studied to see how mass management varies across different parts of the world.

2.3.1 Australia

How excavated soil is managed in Australia differs between the six states. In New South Wales, NSW, both soil and contaminated soil generated from construction and demolition projects are classified as waste and have to be either reused or disposed of correctly (State of New South Wales and the NSW Environment Protection Authority, 2020). One classification of soil that is done in New South Wales is *virgin excavated natural material*. *Virgin excavated natural material* is natural material that has been obtained through excavation or quarrying in areas, free from contamination of manufactured chemicals or by-products from industrial, commercial, mining or agricultural activities. It may not contain sulfidic ores or soils, or other waste. If the material is classified as virgin excavated natural material it can be reused on or offsite without the need for chemical analysis and without requiring a license (Housing Industry Association, 2021). If disposal of the *virgin excavated natural material* is the chosen course of action, it can be transported to a waste facility authorized by the environmental protection agency to receive *virgin excavated natural material*.

Excavated natural material that contains at least 98% natural material, but does not fulfill the requirements of *virgin excavated natural material* is called *excavated natural material* (*Protection of the Environment Operations (Waste) Regulation 2014* (NSW)). *excavated natural material* has to fulfill certain requirements set out in the excavated natural material order 2014 before it can be reused. These requirements include sampling requirements, chemical and other material requirements, requirements for test methods, notifications and recordkeeping and reporting requirements. Additionally, if the excavated soil contains asbestos, it is classified as asbestos waste and must be taken care of in a certain way (*Protection of the Environment Operations (Waste) Regulation 2014* (NSW)). There is soil that is not included in the groups *virgin excavated natural material*, *excavated natural material* or asbestos waste, this soil could be categorized as recovered soil, if it does not include certain contaminants (NSW Environment Protection Authority, 2021). In order to be reused, recovered soils must follow similar requirements as those set for *excavated natural material*, with exception for a difference in testing requirements, chemical limits and attribute limits.

In the state of Victoria, soil that is excavated is called waste soil, and is categorized as industrial waste or priority waste (Environment Protection Authority Victoria, 2021a). Soil that has very low levels of contamination can be used as fill material and is included in the category industrial waste. Reuse of fill material is allowed without any containment. Soil with contamination levels higher than those accepted to be classified as fill material is instead categorized as priority waste. Soil priority waste is in turn divided into five different categories: A, B, C, D and soil containing only asbestos (Environment Protection Authority Victoria, 2021c). Of the lettered categories for soil, A is the most hazardous and D is the least hazardous. Category A soil needs to be treated before it can be disposed of at a landfill. When it is treated it must also be reclassified as either B, C, or D. Soil categorized as B can either be disposed of at a landfill authorized for Category B waste, contained onsite, or be treated and then be reclassified as category C or D soil. Category C soil can either be contained onsite, be disposed of at a landfill authorizing category B or C soil or be treated and reclassified as a category D soil. Category D soil can either be contained, reused on the current site or on a project site, be sent to a landfill authorizing category B, C, or D soils, or be treated and be

reclassified as fill material (Environment Protection Authority Victoria, 2021b). If the soil only contains asbestos it is classified as an own category which must be either contained onsite or sent to an approved landfill for soils containing asbestos.

2.3.2 Finland

One of the aims of Finland's waste management law, Jätelaki (646/2011), is to encourage a circular economy. The law states that a material is to be called waste if the owner has disposed of it, plans to dispose of it or has to dispose of it. A material is not to be called waste, instead a by-product if it arises through a production process whose primary purpose is not to produce the said material and if it fulfills a certain number of criteria. A material should no longer be called a waste if the following five criterion are fulfilled (646/2011):

- It has undergone a recycling procedure.
- It has a purpose for which it is generally used.
- There is a market or demand for the material.
- It meets the technical requirements for the intended use and complies with the regulations applied to the corresponding projects.
- The use of the material does not cause any danger or damage to the environment or human health.

In and around the capital of Finland, Helsinki, many infrastructure projects are being developed due to the ongoing urbanization (Forsman et al., 2013). As a result, a large surplus of excavated soils is being generated. Due to the fact that soft clays and peats are among the most predominant soil types in the country, the excavated soils from construction projects are landfilled and replaced with crushed aggregates. This has led to problems with area shortages for landfills, and material deficit for fill and embankments. Between 2011 and 2013 a pilot project was carried out in Espoo, Finland, where poor quality soil could be recycled through mass stabilization (Forsman et al., 2013). Mass stabilization is a method of adding binders to the soil which hardens and strengthens it. This pilot project is one example of how Finland works to follow its waste management law.

2.3.3 France

Following the European Union's Waste Framework Directive, the French Ministry for environment requested the French Geology Survey and the French National Institute for Industrial and Risks to propose a guidance for the reuse of excavated soils at off-site locations (Blanc et al., 2012). Whether the excavated soil can be reused off-site is based on the French brownfield sites management characterization. Once a site fulfils the French brownfield sites management characterization, soil from that site has a potential to be reused.

At which sites the excavated soil can be reused off-site is based on a soil classification and quality assessment (Blanc et al., 2012). Through this classification and assessment, the soil will then be classified as either natural excavated soil, hazardous excavated soil or contaminated excavated soil. Natural excavated soil can be reused without any limitations at a nearby site within a nearby distance. Hazardous excavated soil must be treated in order for it to be reused, if untreated it must be disposed of at specific licensed landfills. Contaminated excavated soil can be termed as either reusable or marginally

contaminated excavated soil, provided that its quality, whether treated or untreated meets the specified criteria for the intended use. In cases where it is not feasible to identify a suitable reuse option through a cost-benefit analysis, it can be disposed of at landfills or treatment facilities.

There are two different areas where excavated soils can be reused: 1) for road construction in compliance with the standards set by the French nation requirements, and 2) in development projects that require authorization from appropriate regulatory authorities to proceed (Blanc et al., 2012). In order for the soil to be reused within these areas three requirements must be fulfilled. Firstly, the soil quality at the receiving site may not be affected in a negative way. Secondly, groundwater and aquatic ecosystems must not be adversely impacted. Thirdly, the excavated soil must not threaten human health.

2.3.4 Japan

Although reusing excavated soil has been encouraged for several decades in Japan, there has been a cautious shift recently due to increased public awareness and national regulations regarding soil contaminants, particularly in cases involving natural contamination (Katsumi et al., 2019). Certain soils in Japan contain naturally occurring contaminants that surpass the regulatory thresholds set by the Soil Contamination Countermeasures Law, for example arsenic, lead, fluorine and boron. Consequently, for cases where naturally contaminated soils are involved, containment or even landfill has been employed. It has been suggested that these measures may be deemed as too excessive for dealing with naturally contaminated soils. The levels to which the soils are naturally contaminated is significantly lower compared to most artificially contaminated soils. Despite this obstacle, the reuse of excavated soil is still promoted and in several large construction projects it is seen as a necessity.

Surplus soils from excavation activities during construction projects are not classified as waste according to Japanese legal regulations, including the “Waste Management and Public Cleaning Act”, but they do require appropriate management (Katsumi et al., 2019). To promote the use of excavated soils classification and standardization is necessary. In 1994, a standard for excavated soils was proposed by The Ministry of Construction, this standard was later, in 2008, established by the ministry’s successor, MLIT, The Ministry of Land, Infrastructure, Transport and Tourism (Katsumi et al., 2019). The standard categorizes excavated soils into five levels based on factors such as soil type, strength and water content. Apart from classifying the excavated soil, the standard also depicts the appropriate applications for the different classes. If the soil is classified as class five, muddy soil, it can then be categorized as waste. The other four classes are not categorized as waste.

The Ministry of Land, Infrastructure, Transport and Tourism is working on creating increased collaboration between public and private sectors to create successful connections between those who produce excavated soil and those who require it (MLIT, 2018). Furthermore, they present successful matches of excavated soils between private sectors and public sectors dating back to 2015.

2.3.5 United Kingdom

In England and Wales, soil is classified as waste if the holder plans to dispose of it, disposes of it or is obligated to dispose of it (Plimmer, 2023). The soil falls under the regulations of the Waste Framework Directive. In Scotland, the definition of waste differs, soil is not classified as waste until it is transported from the site of origin.

When it comes to natural uncontaminated soil excavated during construction, that is intended for reuse within the same construction project, it is not categorized as waste (Plimmer, 2023). This soil can be freely reused on the same site without being subject to waste regulations. Uncontaminated natural soils that are intended for reuse at a different site require either an exemption from the Environment Agency or a Materials Management Plan constructed through the CL:AIRE Definition of Waste Code of Practice. The exemption is usually limited to 1 000 tonnes. The Materials Management Plan consists of many activities that all must be carried out in order for the plan to be complete.

If a soil is classified as waste and will be transported from the original site it has to be classified as either hazardous waste or non-hazardous waste in accordance with the publication *Technical Guidance WM3: Waste Classification – Guidance on the classification and assessment of waste* (Plimmer, 2023). This classification decides what kind of disposal facility the waste is supposed to end up in. It is illegal to dispose of waste at the incorrect site and thus the waste must be assessed and cannot be assumed to be hazardous or non-hazardous. It is known that the categorization of soils as either hazardous or non-hazardous is not consistently carried out in accordance with the applicable laws and guidelines in the UK (Association of Geotechnical & Geoenvironmental Specialists, 2019). This is most likely due to difficulties in understanding the process as well as its impracticality for cases involving contaminated land where assessments and disposal of waste often occurs rapidly.

2.3.6 Comparison of countries

The way in which different countries define excavated masses as either waste or not varies significantly. Finland, parts of the United Kingdom, and Sweden, share a similar approach to this definition, aligning with the Waste Framework Directive. The influence of this directive is also evident in how Sweden and Finland both employ a consistent method for assessing when waste ceases to be categorized as such and can instead be repurposed.

In France, the laws governing the repurposing of soil are similar to those in Finland and Sweden as they adhere to the principles outlined in the Waste Framework Directive. However, while France's guidance on the reuse of excavated soils at off-site locations similarly follows the Waste Framework Directive, there exist parts in the soil classification that distinguish it from the Nordic countries.

Japan and Australia, in contrast, diverge significantly in their definitions of when soil is classified as waste. Japan refrains from initially defining surplus soil from construction as waste, while the studied states of Australia categorize all excavated soil from construction projects as such.

Both the United Kingdom and Australia have differing laws and regulations regarding mass management within their own nations between the different states/constituent countries.

Two key reasons for why proper mass management is not carried out were identified in the research. In the United Kingdom, it was found that the main reason for lack of reusing excavated soils was most likely due to difficulties in understanding the framework. The research on Japan's mass management showed that soil was not always reused because of their regulations being too strict on determining if natural material is contaminated or not.

In Victoria, Australia, the system for classifying soils in order to be reused is significantly different from the other countries examined. Their classification system contains five classes in which the masses can be treated within class and then reclassified to a less hazardous one, thereby promoting greater flexibility in soil treatment and reuse.

A key distinction between the countries following the Waste Framework Directive, and Japan is the structure of their regulations. According to the Waste Framework Directive, excavated material must meet both technical and environmental criteria in order to be eligible for reuse at a specific site. In Japan, however, this is divided into two laws. It is the Soil Contamination Countermeasures Law that sets the regulations on whether the material is contaminated or not and decides if it can be reused. Furthermore, the Ministry of Land, Infrastructure, Transport and Tourism classifies the material according to technical quality and also proposes if the material can be reused. This division of responsibilities appears less integrated compared to the regulations in other countries.

3 Methodology

The methodology consisted of three main activities: a literature review, the development of Masscycle and case studies. An overview of the method is presented in Figure 3.1.

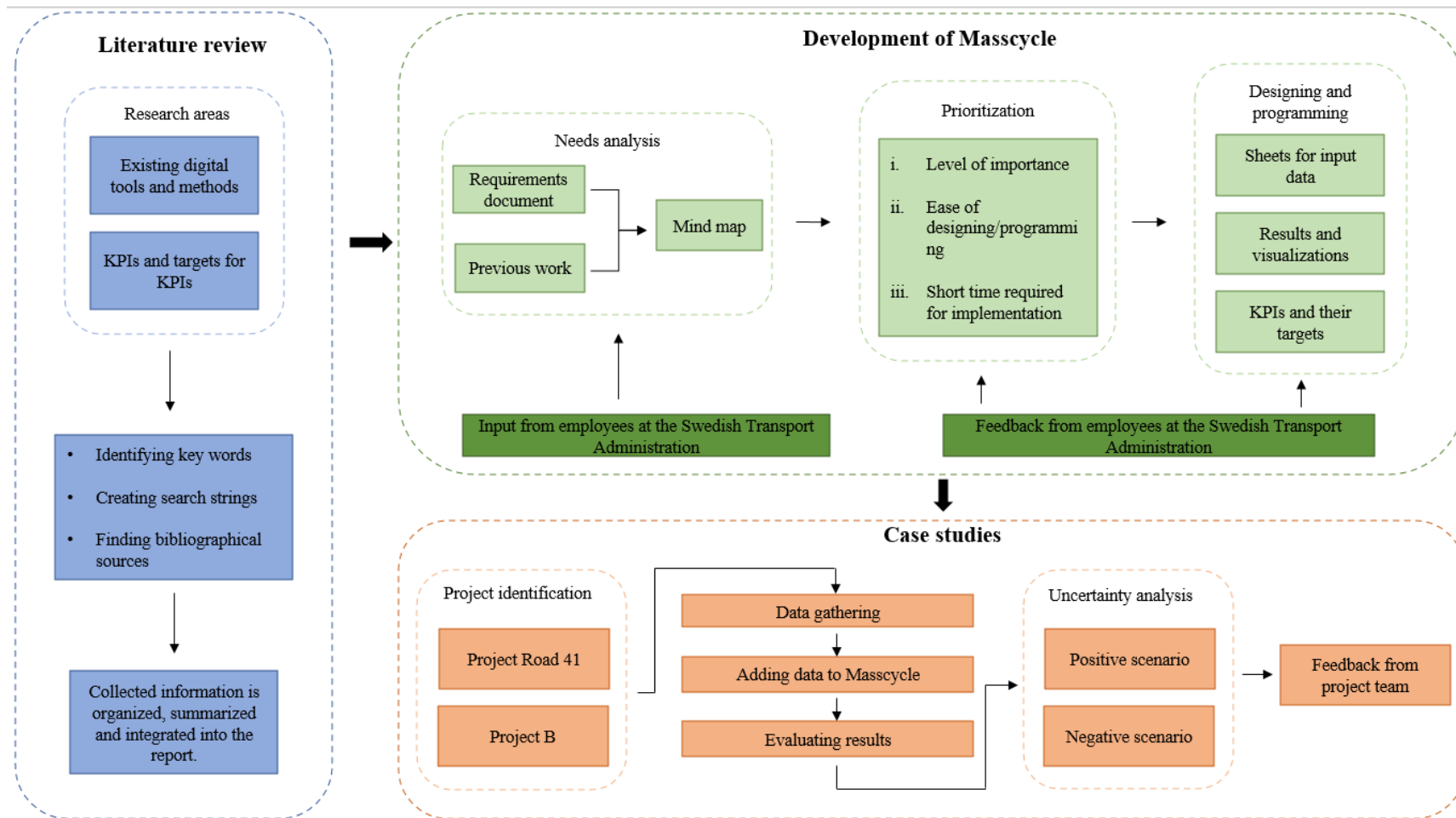


Figure 3.1 Overview of methodology.

3.1 Literature review

This chapter outlines the methodology employed to conduct the literature review for this research. The following two questions were answered in the literature review:

- Are there any existing digital tools used for the planning of mass management?
- Which KPIs and targets for KPIs are relevant regarding the planning of mass management?

The first step in the literature review process was the identification of key words and phrases related to the research questions. Key words were identified in both English and Swedish to receive more results. These key words, presented in Table 3.1, served as the foundation for effectively navigating through academic literature and finding relevant sources. The selection of appropriate key words was critical in ensuring the accuracy and relevance of the literature collected. The key words together with the Boolean operators “AND” and “OR”, as well as asterisk to allow for plural meanings, were then used to create search strings. The search strings were used to find relevant sources in databases and search engines.

Multiple bibliographical sources were consulted to ensure a comprehensive review of the existing literature. These sources included databases, journals, books, conference proceedings, and reputable websites. The data bases that were used in the literature search are listed below:

- Google Scholar
- ScienceDirect
- Scopus
- Web of Science
- SpringerLink
- Research.chalmers.se
- DiVA portal
- DiVA
- Trafikverket
- IEEE.

In addition to finding literature through search strings, snowballing was used. Snowballing refers to using reference lists in literature to identify other useful sources (Badampudi et al., 2015). The final step in the literature review process was the analysis of the identified research. This analysis consisted of determining how the identified digital tools and methods could be used as inspiration to Masscycle and to what extent mass management was incorporated into the tool. For the KPIs and targets for KPIs, the analysis consisted of identifying whether they were possible to incorporate into Masscycle and how measurable they were. The collected information was organized, summarized, and integrated into the report.

Table 3.1 Key words used when searching for literature.

Questions	Key words (English)	Key words (Swedish)
Are there any existing digital tools used for planning of mass management?	Digital tool, tool, method, planning, project, infrastructure project, construction, mass management, mass	Masshantering, digitala verktyg, verktyg, projektering, massor, metod,

	handling, excavated soil and rock	planering, infrastruktur
Which KPIs and targets for KPIs are relevant regarding planning of mass management?	Key performance indicator, targets for key performance indicator, planning, project, infrastructure project, construction, mass management, mass handling, excavated soil and rock	Nyckeltal, målvärde, masshantering, projektering, planering, jordmassor, bergmassor, schaktmassor, indikator

3.2 Development of Masscycle

Masscycle was developed through three stages: a needs analysis, a prioritization, and designing and programming of the tool, which can be seen in the green section of Figure 3.1. A needs analysis was carried out, through a brainstorming session, to ensure that the tool included all essential parts. The technique that was used to perform the brainstorming was mind mapping. Research shows that the use of mind mapping in brainstorming increases the number of ideas that arise and improves the quality of them (Paykoç et al., 2004). Masscycle was set as the head topic in the mind map and a few subtopics were identified. From each subtopic, different needs were listed. To make sure the needs analysis covered all relevant needs, three inspirational inputs were included to the brainstorming session. One inspiration source was the requirements document for mass management, which covers the demands that the Swedish Transport Administration has on its consultants. Some ideas in the needs analysis arose from reconciliations with employees within mass management or project management at the Swedish Transport Administration as well as from previous works regarding mass management. The previous work included a bachelor thesis (Borre et al., 2022) and a precursor tool (Jansson & Olsson, 2023).

The second stage encompassed the prioritization of the subjects that were identified in the needs analysis. This prioritization was carried out through a simplified multi criteria analysis. In the multi criteria analysis the needs from the brainstorming session were listed and scored from 1-10 based on three different criteria. The criteria were

- i. How important is it that the need is incorporated in Masscycle?
 - 10: Masscycle would be incomplete if the need is not implemented.
 - 5: Masscycle would benefit from the need, but it can also be fulfilled in other ways.
 - 1: The need can be fulfilled in an easier or better way, than it would be in Masscycle.
- ii. How easy is it to design/program the need in Masscycle?
 - 10: The need is very easy to incorporate in Masscycle.
 - 5: The need is neither hard nor easy to incorporate in Masscycle.
 - 1: The need is very difficult to apply in Masscycle.
- iii. Is the need something that will take a short time to implement in Masscycle?
 - 10: The need requires a short amount of time.

5: The need requires a medium amount of time.

1: The need requires a long amount of time.

Depending on how important the criteria were, they were weighted. The first criterion, i, was most essential as some needs may be part of the objectives for Masscycle. Because of this, it received the weight 1. The second criterion, ii, was not as essential as the first, because both needs that are easy to satisfy and hard to satisfy should be attempted to be incorporated in Masscycle if they are important. It received the weight 0.5. The third criterion, iii, received the weight 0.2 as it is less essential than level of importance and ease of programming/designing. The scoring of the needs for the different criteria was then multiplied by their weights and summed up to create a weighted score. The weighted scores were then compared and a ranking was created, where the need with the highest weighted score got the lowest rank. The ranking indicated the order of the prioritization. The prioritization, specifically the scoring, was conducted with assistance from the consultations held with employees at the Swedish Transport Administration.

Once the prioritization was complete, the designing and programming of the tool started. This included creating the sheets for input data, results and visualizations, KPIs and targets for KPIs. This stage involved deciding how to incorporate the chosen subjects from the prioritization in the Excel tool. The order of the different subjects needed to be done correctly for calculations to succeed and to create a reasonable flow for the user. Designing the tool in a way to make sure that the user could understand the different functions was also important in this stage. Throughout the whole stage, the programming was carefully carried out to avoid errors hindering the program from creating correct results.

In the literature review several KPIs and targets for KPIs were identified. A selection process was conducted to decide which of the recognized KPIs would be included in the Excel tool. The KPIs were included to show the user what the project accomplished in comparison to the targets for KPIs. The criterion for implementation was that there would be enough input data from the results sheets to produce useful information. If there was a small lack of input data, then the KPIs were changed. They were changed so that the available data from Masscycle was enough to create useful results. If not possible, they were not implemented in Masscycle. The digital tools identified in the literature review were used during this stage as inspiration to the design and function. During the whole designing and programming phase, regular reconciliations with employees at the Swedish Transport Administration were held.

3.3 Case studies

Once the Excel tool was fully designed, two case studies were carried out to test its functionality. This was done through testing the tool on two different road infrastructure projects, project Road 41 and project B. The case studies consisted of three parts, which were carried out separately for the two different infrastructure projects. The first part consisted of project identification and data gathering. The second part consisted of adding the data from the projects as input to Masscycle and evaluating the results. The third part consisted of an uncertainty analysis.

The project identification involved listing ongoing road infrastructure projects in Sweden and contacting project managers to ensure permission for testing Masscycle. Furthermore, project engineers were contacted for access to project databases. When access was given to the data bases, the process of gathering data began. Documents containing information regarding mass quantities and mass classifications were identified and data was extracted.

In the second stage of the case study, the data gathered from the infrastructure projects was entered into Masscycle. During this stage, the following questions were evaluated:

- Is the input data accessible?
- What data could not be found?
- What assumptions were made?

During this phase of testing Masscycle, it was also studied that all the functions and features worked properly. If errors were discovered, they were fixed.

An uncertainty analysis was conducted for each of the road infrastructure projects, in order to evaluate the functionality of Masscycle. The purpose of the analysis was to get an understanding of how large the effect of uncertain input parameters has on the result. The analysis was done by evaluating two different scenarios of the projects. For each project, the compilations and KPIs of the three outcomes of Masscycle (original and two scenarios) were compared. How the uncertainty of the input parameters can affect the result was analyzed by comparing the scenarios within one project.

Once the case studies were completed, the results from Masscycle were compiled and presented to the project teams. Feedback was gathered from the project teams regarding their satisfaction with the results, doubts about the assumptions made and the usefulness of uncertainty scenarios.

3.3.1 Project Road 41

Road 41 will be reconstructed between Sundholmen and Björketorp in a new stretch (Agnefjärd, 2024). The current stretch follows a stream called Viskan, which is at risk of landslides (Trafikverket, 2014). This risk is caused by the properties in the surroundings, such as low stability soil, bank erosion around the stream and the load from the road. Because of the instability, as well as to increase safety and accessibility, a new stretch will be built (Agnefjärd, 2024). With this reconstruction, 13 open level crossings will be removed and two controlled level crossings will be constructed. In addition, two private roads will be constructed. The construction for project Road 41 is split and carried out by two contractors. In Masscycle, the part of the project containing the construction of the private roads and controlled level crossings is evaluated. There were two reasons for this part of the project being evaluated through Masscycle. Firstly, the low quantity of masses decreased the time needed for input and analyzation in Masscycle and instead allowed for a higher focus to detail. Secondly, the different constructions making up the project tested how Masscycle would work on a non-linear civil work.

Table 3.2 presents the two scenarios that were created to evaluate different outcomes of the project. Both scenarios were exaggerated in order to ensure a clear change in

result. The first scenario represents a positive change and the second scenario represents a negative change.

Table 3.2 Description of scenario 1 and 2 for project Road 41 presented together with an explanation of the reclassification.

Scenario 1 <i>Positive</i>	Scenario 2 <i>Negative</i>
A reclassification of the emerged masses was carried out. The masses were reclassified with a lower contamination level than the initial classification. This was done by reclassifying the masses at level crossings as below KM.	A reclassification of the emerged masses was carried out. The masses were reclassified as masses with less desirable geotechnical properties than the initial classification. This was done by reclassifying the masses with material type 5A to material type 6A, as well as reclassifying masses with material type 5B to material type 6B.

3.3.2 Project B

Due to confidentiality, the second evaluated project is referred to as project B. Project B consists of a reconstruction of an approximately 20km long highway section in a new stretch. It also consists of construction of private roads and other public roads in connection to the highway.

In the PM Mass Management, the emerged masses were displayed in a bar chart. Separately, an Excel-file was provided with data for the bar chart. To include emerged masses in Masscycle, the data from the Excel-file was extracted and used as input consequently, Masscycle received exact quantities of emerged masses for each section. Additionally, the Excel-file only included the masses from the highway and not the other public and private roads which were also part of the project, and therefore these masses could not be included in Masscycle.

In the PM Mass Management and the provided Excel-file, the material type classification was not detailed enough for Masscycle. Instead of classifying masses according to specific material types, masses were specified in groups of material types. Group one consisted of material type 2 and 3B, while group two consisted of material type 4B and 5A. Therefore, the uncertainty scenarios were designed to evaluate cases with differing material types, which are presented in Table 3.3. Scenario 1 represents a positive scenario, while scenario 2 represents a negative scenario. For the initial classification, the masses were split evenly between the material types in group one and group two.

Table 3.3 Description of scenario 1 and 2 for project B presented together with an explanation of the reclassification.

Scenario 1 <i>Positive</i>	Scenario 2 <i>Negative</i>
<p>A reclassification of the emerged masses was carried out. The masses were reclassified as masses with more desirable geotechnical properties than the initial classification. This was done by reclassifying all of the masses in group one as material type 2, and reclassifying the masses in group two as material type 4B.</p>	<p>A reclassification of the emerged masses was carried out. The masses were reclassified as masses with less desirable geotechnical properties than the initial classification. This was done by reclassifying all of the masses in group one as material type 3B, and reclassifying the masses in group two as material type 5A.</p>

4 Results

This chapter includes results from the literature review, an overview of the development of Masscycle and the performed case study.

4.1 Findings from literature review

The literature review was conducted to investigate existing tools and methods within the area of mass management as well as KPIs and targets for KPIs related to mass management. It was discovered that internationally, many different terms are used for the topic of mass management which led to snowballing being a better technique for finding relevant literature. In Swedish, there were not many different terms for mass management, but there is little research about the topic. Therefore, snowballing from the literature found with the help of search strings proved to be useful. Overall, the search strings in Swedish proved to increase the number of relevant hits.

4.1.1 Existing digital tools and methods for mass management

From the search strings used to identify digital tools or methods, three different categories of hits were identified. The first category consisted of relevant hits. One relevant hit was found using English search strings. Seven relevant hits were found using Swedish search strings and an additional four were found through snowballing. Of the twelve relevant hits, one was white literature. The second category consisted of sources within civil engineering works, but outside of the topic mass management. The third category consisted of nondigital tools in civil engineering works and digital tools within other industries.

Eight different digital tools and methods developed for mass management, were identified. Table 4.1 summarises the identified tools regarding their purpose, in what phase they were designed to be used, which input parameters are required, and the results that are given from the tool/method. The following text describes each tool and method more in detail. Finally, Table 4.2 summarises how the different acted as an inspiration for Masscycle and whether they could serve as input to or get input from Masscycle.

Table 4.1 Overview of the examined digital tools and methods for mass management.

Tool/ method	Purpose	Phase	Input	Results
Prototype tool (Andersson-Sköld et al., 2022)	To support the reporting of mass management in the Swedish Transport Administration's projects.	Planning phase	Project cost, contamination levels of masses and quantity of required masses for the project	KPIs and results in the form of some demands from the Swedish Transport Administration's requirements document
Geokalkyl Pro (Lindgren et al., 2022)	Study mass management, costs and climate impact of roads and railways, and compare different options.	Early stages of the planning phase	Geographical location of the project, height models, information about the surrounding environment such as road networks, waterways, soil depth and soil type	Cost, CO ₂ -eq and energy for mass management, geotechnical solutions, asphalt, bridges, tunnels and intersections
SmartMass	Make mass management simpler and contribute to a more sustainable branch of industry (Tyréns, n.d-a).	Planning phase (Tyréns, n.d-b)	Category A or B masses, quantities of soil and rock, distance for transportation within the work area, to recipients and for fill masses (Tyréns, n.d-b)	Visualizations, how cost and carbon emissions can be reduced for transportation, machines & labour, purchased material, and facilities for disposal of excavated masses (Tyréns, n.d-a)
Klimatkalkyl (Toller, 2020)	Calculate energy use and climate effects from infrastructure projects from a life cycle perspective.	Planning phase and construction phase	Construction parts, material and/or sub-operations or pre-defined maintenance measures	Emission factors in terms of CO ₂ -eq and energy use

VegLCA	Used to study climate impact (Dahlstrøm Andvik et al., 2022) of all Norwegian projects over 51 MNOK (Statens Vegvesen, n.d).	Detailed planning phase and early planning phase (Dahlstrøm Andvik et al., 2022)	Quantities and lengths of tunnels, bridges and roads/railways, quantity of gasoline, diesel and electricity used for transportation of masses and working vehicles on site, data about worker transportation, and detailed data about construction elements (Hammervold, 2024)	Climate impact from the whole process of the construction project, including masses and costs (Dahlstrøm Andvik et al., 2022)
DynaRoad (Hillman & Dahlström, 2014)	Developed for planning of mass management, scheduling, resource planning, traffic planning and creating forecasts for production in large-scale and highway projects.	Planning phase, construction phase and follow-up	Quantities of masses, distances, costs, road models, associated roadside areas and connections	Visualizations and tables containing information about mass management, line-of-balance and comparison between planned and final results
GEOSECMA for ArcGIS (Sokigo, n.d)	Combine databases and information from all areas of operations as a foundation for decision-making.	Different phases depending on what module of GEOSECMA that is used	Data concerning the municipality e.g. road networks, real estate, traffic, detailed development plan	Support for decision-making
Unmanned aerial systems and vehicles (Wang et al., 2017)	Calculating earthwork volumes in civil engineering and agriculture.	Construction phase	Images from digital cameras	Earthwork volumes

Table 4.2 Description of how the different tools/methods can serve as inspiration to Masscycle and if collaboration with Masscycle is possible.

Tool/method	Inspiration for Masscycle	Collaboration with Masscycle
Prototype tool (Andersson-Sköld et al., 2022)	<ul style="list-style-type: none"> • Excel-based • Sheet division according to requirements document • Design 	Not possible as prototype tool does not include geographical division
Geokalkyl Pro (Lindgren et al., 2022)	<ul style="list-style-type: none"> • Design • Geographical division • Compilation sheets 	Possible input to Masscycle
SmartMass (Tyréns, n.d-a)	<ul style="list-style-type: none"> • Scenario-based diagrams • Design of visualizations 	Further research would need to be done to evaluate if method could result in input for Masscycle
Klimatkalkyl (Toller, 2020)	None, Klimatkalkyl and Masscycle have different purposes	Further research would need to be done to evaluate how Masscycle and Klimatkalkyl could be compatible with each other
VegLCA (Dahlstrøm Andvik et al., 2022; Statens Vegvesen, n.d)	<ul style="list-style-type: none"> • Excel-based • Design • Visualizations 	Not possible due to differing purposes
DynaRoad (Hillman & Dahlstrøm, 2014)	<ul style="list-style-type: none"> • Design of some visualizations 	Not possible due to differing purposes
GEOSECMA for ArcGIS (Sokigo, n.d)	None, GEOSECMA and Masscycle have different purposes	Not possible as input data differs too much
Unmanned aerial systems and vehicles (Wang et al., 2017)	None, the method using unmanned arial systems and vehicles is too different from Masscycle	Further research would need to be done to evaluate if method could result in input for Masscycle

4.1.1.1 Prototype tool

A prototype of a tool that can be used for mass management with a focus on presenting indicators and KPIs was designed by Andersson-Sköld et al. (2022). The tool considers if the masses are useful for construction purposes concerning technical requirements and the magnitude of contamination. The prototype was developed in a pilot project to be used during the Swedish Transport Administration's procurements. Regarding fulfilling the demands in the requirements document by the Swedish Transport Administration, it is designed to fulfil the demand of reporting the quantities of masses, present in the requirements document from 2013. The prototype tool asks the user to supply information about project cost, contamination levels of masses and quantity of

required masses for the project. After that, the tool calculates and provides the user with results regarding the project's mass balance. In the next step, the user is asked to answer a few questions, regarding the different demands in the requirements document. On the last sheet a table with results regarding the demands in the requirements document and KPIs is presented.

Several parts of the design of the prototype inspired the design of Masscycle, such as that the prototype is implemented in Excel, the sheets in the prototype are divided according to the demands in the requirements document, it has a specific sheet for the matching of emerged and needed masses, and some of the KPIs. When the prototype was evaluated, it was apparent that using Excel was a good approach to easily present results and visualizations regarding mass management. Some smaller parts of the prototype were used as inspiration to Masscycle as well, these include the red colour (the Swedish Transport Administration's profile colour) in the heading on the different sheets, and that grey squares indicate automatically calculated cells.

In the requirements document it is stated that the masses should be divided according to geographical area and that all properties of the masses should be displayed (Trafikverket, 2022b). In the prototype the emerged masses are not connected to a specific area of emergence, and it is not possible to combine different properties of the masses, such as contaminants, material type and invasive species. In Masscycle it was deemed necessary during the needs analysis to include a geographical division for both the emerged and the needed masses. It was also regarded as necessary to include the possibility of describing all possible combinations of properties of the emerged masses, as this coincides with the requirements document.

4.1.1.2 Geokalkyl Pro

Geokalkyl Pro is a tool developed by the Swedish Transport Administration and AFRY to study mass management, costs and climate impact of roads and railways (Lindgren et al., 2022). The tool makes it possible to compare different line options for infrastructure projects. The tool was developed to be used in the early stages of the planning phase when there is little to no knowledge about the project site. Results from the application can be used to study the outcome of different geotechnical measures and optimize the mass balance for the different line options, which can be used to find the optimal line. The tool proposes suitable geotechnical measures depending on soil type, soil depth and embankment height for the provided line. It evaluates the quantity of emerged masses and required masses, as well as whether the masses are suitable for construction purposes. In Geokalkyl Pro, it is possible to present results graphically, which provides users with the opportunity to get an overview of the project's mass management, transportation, and potential distribution of contractors. This feature also simplifies the identification of troublesome geographical locations in the civil engineering works.

Geokalkyl Pro inspired both the design and function of Masscycle, for example, the geographical division of the masses, the easily understandable design of the large tables with data, and the inclusion of compilation sheets including visualizations and results regarding a project's mass balance. Geokalkyl Pro and Masscycle are not used to receive results concerning the same subject, this is evident since the results from Geokalkyl Pro can be used as input to Masscycle. Geokalkyl Pro provides the project

with an overview of the masses at an early stage. Therefore, some differences between Geokalkyl Pro and Masscycle exist, these include soil characterization, cost and climate impact. In Geokalkyl Pro the soil is described according to geotechnical terrain classes which are based on soil types (Lindgren et al., 2022). In Masscycle the masses are specified using material types from AMA Anläggning 2023. Geokalkyl Pro provides results regarding costs and climate impact while Masscycle does not. For future development of Masscycle, including costs and climate impact would be necessary to ensure that the tool includes all aspects of circularity.

4.1.1.3 SmartMass

SmartMass is an application designed to make mass management simpler, and thereby contribute to a more sustainable branch of industry (Tyréns, n.d-a). It uses advanced calculations to study how climate effects and the cost of mass management can be reduced and visualizes alternative solutions. Calculations and results are divided into four categories: transportation, machines & labour, purchased material, and facilities for disposal of excavated masses. In the transportation category carbon emissions and transportation costs for the vehicles are accounted for. Machines & labour include carbon emissions from the machines and the cost of labour. In the purchased material category, purchase costs and carbon emissions for supplied soil and rock masses, asphalt, geotextiles and sheet pilings are presented. For disposal of excavated masses, carbon emissions to and from the facilities are visualized, as well as the disposal cost. With the tool SmartMass it is also possible to compare different scenarios with each other through visualizations, with regards to cost and carbon emissions (Tyréns, n.d-a). SmartMass acted as inspiration to Masscycle through scenario-based diagrams and how some visualizations were designed.

4.1.1.4 Klimatkalkyl

Klimatkalkyl is a web-based tool developed by the Swedish Transport Administration (Toller, 2020). The tool was developed to enable consistent calculations of energy use and climate impact from construction and maintenance of transport infrastructure. Klimatkalkyl is used during the planning phase and the construction phase. Four different cases exist depending on what type of project it is and which input data that is accessible. The first three cases are developed to be used for the planning of the construction of projects, while the fourth considers the planning of the maintenance of projects. The input for the first case is construction parts, such as tunnels, bridges and roads. For the second case the input is specific elements for construction, such as material and/or sub-operations. The third case is used when both input types are accessible. For the fourth case, input data regarding pre-defined maintenance measures are needed. In all four cases the results are emission factors in terms of CO₂-eq and energy use.

There were no components of Klimatkalkyl that were an inspiration to Masscycle, because of the differing purposes between the tools. Further studies should be done regarding how the tools could be compatible with each other, since the climate effects and energy use due to mass management are an important part of circular project planning.

4.1.1.5 VegLCA

VegLCA is a Norwegian tool developed by Asplan Viak for the Norwegian Public Roads Administration (Dahlstrøm Andvik et al., 2022). All road and railway infrastructure projects over 51 million NOK must use VegLCA to calculate greenhouse gas emissions (Statens Vegvesen, n.d). The tool is used during the detailed planning of road and railway infrastructure projects (Dahlstrøm Andvik et al., 2022). It is divided into two parts: an overview tool and a detailed tool. The overview tool can be used when there is no detailed data for the infrastructure project, while the detailed tool is used in the late phase of the infrastructure project. With the application, it is also possible to prepare tenders for construction work, as well as calculate the environmental impact of construction activities, including masses.

Three components of VegLCA were an inspiration to Masscycle. These were the Excel-based platform, the results being presented as visualizations, and the grey cells indicating that calculations are done automatically.

4.1.1.6 DynaRoad

DynaRoad, developed in Finland, was designed to plan and follow-up mass management in large infrastructure projects (Mireé & Nordin, 2014). The application is divided into three modules: Plan, Schedule and Control. The planning module is designed to provide the user with the most optimal distribution of masses to reach mass balance. The scheduling module creates a schedule for the project. The controlling module is used to control and follow-up on the progress of the project and compare it to the initial plan. DynaRoad was acquired by Topcon in 2013 (Topcon, 2013). The design of some of the visualizations in Dynaroad was an inspiration to Masscycle.

4.1.1.7 GEOSECMA for ArcGIS

GEOSECMA for ArcGIS is a tool used by municipalities for support concerning map and blueprint plans (Sokigo, n.d). In the map and blueprint plans road networks, properties, traffic-related questions, pipe networks, zoning and green infrastructure are shown. One municipality in Sweden uses GEOSECMA for mass management, where information about the project area is used as input to the application to ease the workload when advancing to the next planning stage (Axelsson, 2023). The municipality hopes that the use of GEOSECMA will increase the knowledge regarding mass management, within their geographical area. GEOSECMA did not provide any inspiration for Masscycle as the tools have different purposes.

4.1.1.8 Unmanned aerial systems and vehicles

Estimation of earthwork volumes can be done using the method of unmanned aerial vehicles and unmanned aerial systems (Wang et al., 2017). The unmanned aerial systems capture images from above using digital cameras, which then are converted to highly precise three-dimensional models. The three-dimensional models are processed and the earthwork volumes are calculated. The method of estimating earthwork volumes through unmanned aerial systems and vehicles did not provide any inspiration for Masscycle because of the much differing way they are designed. To evaluate if there could be a collaboration between the method and Masscycle, further studies would be

needed to see if the earthwork calculations from arial systems and vehicles could be used as input in Masscycle.

4.1.2 KPIs and targets for KPIs for mass management

International literature regarding the KPIs could not be identified, using any combination of the key words to build search strings. The hits from the English search strings only related to KPIs from other aspects of civil engineering works than mass management. From Swedish sources, four studies could be identified which described KPIs. These were all found using the Swedish search strings and are all grey literature.

Results from a study conducted by Rosén et al. (2020) include examples of KPIs that can be used as a part of the decision support and assessment of a project's mass management. KPIs can provide the possibility of comparing different recycling strategies and create incentives for increased recycling. The project's performance can be assessed by comparing the results from KPIs at various stages of the project.

A feasibility study was performed by Andersson-Sköld et al. (2022) to identify indicators and KPIs that could be used to enhance mass management within the Swedish Transport Administration's projects. Several of these identified KPIs were collected from the previously mentioned study by Rosén et al. The idea for the identified KPIs is that they should be included in the procurements at the Swedish Transport Administration, where they can be used for requirements and incentives regarding mass management. Over the long term, the requirements and incentives are intended to encourage contractors to adopt a more circular, sustainable, and innovative approach to mass management.

The county of Stockholm has developed a strategy for mass management to increase resource efficiency (Ryding et al., 2023). The strategy is also meant to create a consensus within the county, regarding barriers and their target scenario for mass management. To reach the target scenario three sub-targets were established: 1) broad cooperation within the region to secure competition neutrality and equal opportunities, 2) mass management and transportation are carried with the lowest possible environmental impact, and 3) a resource-efficient, circular and socioeconomically optimized mass management. The third sub-target specifies that circularity should be measurable and provides examples of KPIs.

Axelsson (2023) performed a study on a Swedish municipality with a need for increased sustainable mass management. The municipality was compared to two other municipalities which were identified to have a sustainable approach to mass management. The aim of the study was to identify key factors for improving mass management in the municipality, as well as presenting an implementation strategy for the key factors to reach the established targets. The key factors are not defined in the same way as KPIs are. An example of a key factor is *Prioritizing the planning of transports and their load during the procurement stage*. Key factors describe subjects that need to be developed to reach the targets for sustainable mass management. Several KPIs could represent one key factor, therefore, the targets described in the study are applicable to use for KPIs from other studies describing that subject.

For the identified studies, KPIs and targets for KPIs are presented in Table 4.3. The KPIs from the different studies are presented in individual columns while the targets for KPIs are presented together in one column. When KPIs from different studies are similar, they are placed on the same row together with the corresponding target. The last column presents how the KPIs and targets were applied in Masscycle.

Table 4.3 Description of different KPIs and targets for KPIs, and how they were applied in Masscycle.

KPI	KPI by Rosén et al. (2020)	KPI by Andersson-Sköld et al. (2022)	KPI by Ryding et al. (2023)	Target for KPI by Andersson-Sköld et al. (2022) ^a and Axelsson (2023) ^b	KPI and target for KPI in Masscycle
1	Project economic and socio-economic unit costs, calculated in SEK per tonne of soil masses	Project cost per tonne emerged masses within the project			Mass management cost per meter of project Target: Manual
		Project cost per tonne recycled masses			
		Project cost per tonne waste produced by the project			
2	The relation between tonne recycled masses (on-site and off-site) and tonne virgin masses	The relation between tonne recycled masses on site and tonne masses taken from quarries to the project			Not used, because of the similarity between KPI 2 and KPI 3.
3	The relation between tonne virgin masses taken from quarries and the entire quantity of tonne virgin masses (shows that virgin	The share of total required masses for the project, which have been met with recycled masses or surplus masses from		100% ^a Increased use of resources already on-site ^b	The relation between internal resources in m ³ and total needed masses in m ³ Target: 100%

	masses can be from both quarries and surplus masses from infrastructure projects)	within the project or from external projects		Increased recycling ^b	The relation between masses that have been met by recycled masses in m ³ (from within the project or from external projects) and total needed masses in m ³ Target: 100%
4	The relation between tonne masses sent to landfill by the project and the total capacity of the landfill	The relation between tonne masses sent to landfill by the project and the total capacity of the landfill		↓ (as low as possible) ^a	The relation between tonne masses sent to landfill by the project and the total capacity of the landfill Target: ↓
5	The relation between tonne recycled masses (both on-site and off-site) and tonne excavated masses	Share of emerged masses recycled on site		↑ (as high as possible) ^a Maximize the use of resources ^b	The relation between recycled masses (internally and externally) in tonnes and emerged masses in tonnes Target: 100%
6	Sampling costs for the project per tonnes of recycled masses (on-site and off-site)	Sampling costs for the project per tonnes of recycled masses (on-site and off-site)			Sampling costs for the project per tonnes of recycled masses (on-site and off-site) Target: Manual
7	Sampling costs for the project per total masses in tonnes				Not used, it is unclear what the definition of total masses is.

8		Sampling costs for the project per tonnes of recycled masses within the project			Sampling costs for the project per tonnes of recycled masses within the project Target: Manual
9		Sampling costs for the project per tonne of waste produced by the project			Sampling costs for the project per tonne of waste produced by the project Target: Manual
10		Sampling costs for the project per total emerged masses in tonnes within the project			Sampling costs for the project per total emerged masses in tonnes within the project Target: Manual
11		Share of total project cost that is the sampling cost			Share of total project cost that is the total mass management cost Target: Manual
12		Share of the total consumption of virgin masses that comes from quarries		0% ^a	Not used, since the share of the total consumption of virgin masses that does not come from quarries is already a KPI (#3)
13a		Share of total required masses for the project which are met by virgin masses from quarry	Share of total required masses for the project which are met by virgin masses from quarry	0% ^a	The relation between virgin masses from quarry in m ³ and total needed masses in m ³ Target: 0%

13b		Share of total required masses for the project which are met by virgin masses from quarry	Share of total required masses for the project which are met by virgin masses from quarry	0% ^a	The relation between externally needed masses in m ³ and total needed masses in m ³ Target: 0%
14		The share of emerged masses which meet the technical requirements and have been recycled, on site or off site		100% ^a	The relation between internal resources in tonnes and masses identified as suitable for the project in tonnes Target: 100%
15		All facilities for disposal of excavated masses approved		Yes ^a	The relation between approved disposal site permits and all applied disposal site permits Target: 100%
16		Share of recycled masses within the project that needed treatment			The relation between total recycled masses in tonnes within the project and recycled masses that needed treatment in tonnes Target: Manual
17		Share of purchased masses that have been pesticide-sprayed			Not used, decided in consultation with an employee at the Swedish Transport Administration
18		Share of vehicles transporting invasive species			Not used, decided in consultation with an employee at the Swedish Transport Administration

19			Share of vehicles driving with empty load	Decreased transportation ^b	Not used, decided in consultation with employee at the Swedish Transport Administration
20		KPI considering health criteria in regards to number of transportations			Not used, unclear KPI
21		KPI considering environmental and ecological aspects	KPI considering environmental aspects		Not used, unclear KPI
22		KPI considering sustainability criteria in regards to assessed health effects			Not used, unclear KPI
23		KPI considering the overall benefit versus undesired effects			Not used, unclear KPI
24				Increased cooperation ^b	Not used, difficult to measure
25				Optimize use of area ^b	Not used, difficult to measure
26				Strategic planning during early stages ^b	Not used, difficult to measure
27				Clear routines to follow ^b	Not used, difficult to measure
28				Increased knowledge and involvement ^b	Not used, difficult to measure

4.2 Masscycle

4.2.1 Needs analysis

The results from the needs analysis are presented in the form of a mind map in Figure 4.1. The mind map consists of six topics, each summarizing a different category of needs. The topic *circularity measurements* includes ways to measure the level of circularity within the project, through KPIs and targets for KPIs.

Sustainability includes measuring the amount of carbon emissions due to mass management, the number of transports required and the share of electric vehicles.

Presentation of resources highlights if masses are resources or waste and how this can be visualized. The needs include a classification of the masses in the project as internal, external or potential resources. Another classification that is listed as a need is waste classification. The need pie charts and diagrams are included as a suggestion of how resources and non-resources can be presented.

The topic *economy* focuses on different parts of mass management such as landfill disposal, reloading areas, transportation and buying and selling of masses, which all can have a significant impact on the cost of the project.

Fulfil demands in the requirements document consists of different aspects stated in the Swedish Transport Administration's requirements document. These aspects contain the classifications from AMA Anläggning 23, contamination level, invasive species and a guaranteed market. A guaranteed market is required for masses to be considered as external resources. Presenting data in tables and visualizations and including time and geographical aspects is demanded in the requirements document.

Functions describe different actions that should be possible to perform through Masscycle as well as design and layout properties. It should be an Excel tool, where manual inputs by the user are possible, an automatic matching of needed and emerged masses is executed and it should include a compilation of the project.

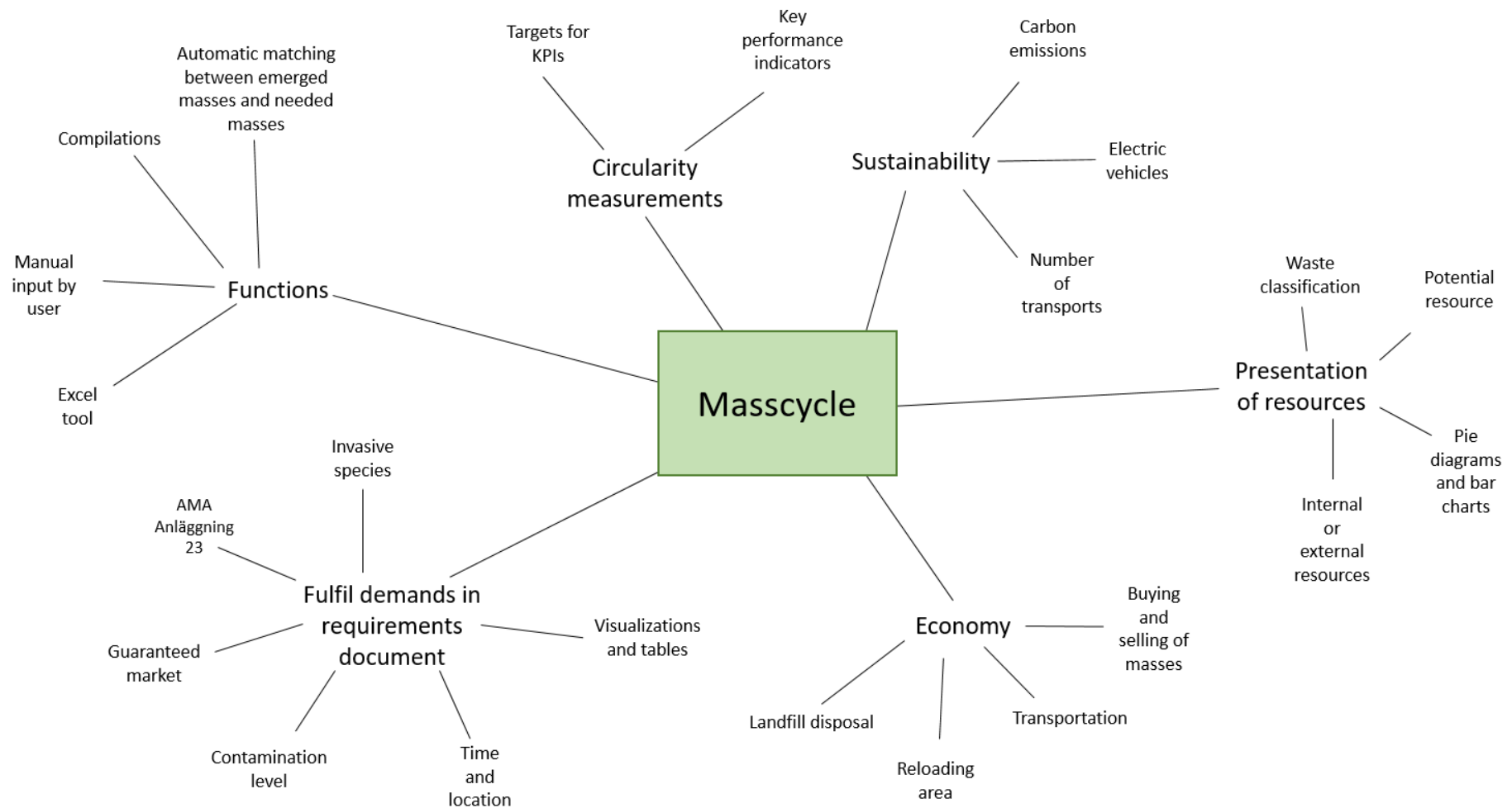


Figure 4.1 Presentation of the results from the brainstorming session.

4.2.2 Prioritization

The results from the prioritization are presented in Table 4.4. The needs listed in the table are the same as from the brainstorming session. These needs were scored according to three different criteria, which were weighted as followed: level of importance – 1, ease of programming/designing – 0.5 and short time consumption for implementation – 0.2. Overall it can be seen that the needs connected to fulfilling the demands in the requirements document as well as circularity measurements received the highest rank. Since fulfilling the demands in the requirements document and including KPIs are a part of the objectives of Masscycle, the needs regarding these topics were scored as the highest level of importance (10). During consultations with employees at the Swedish Transport Administration, several stated that the needs regarding economy were not as important as the other needs, because they are not a part of a PM Mass Management. Because of this they were scored low in the criterion regarding importance, which resulted in low weighted scores.

Table 4.4 Results of the prioritization.

Criteria	Level of importance	Ease of programming / designing	Short time consumption for implementation	Weighted score	Rank
Weight	1	0.5	0.2		
Needs					
Invasive species	10	10	9	16.8	1
Excel tool	10	10	9	16.8	1
Pie diagrams and bar charts	10	10	8	16.6	3
AMA Anläggning 23	10	9	8	16.1	4
Targets for KPIs	10	8	8	15.6	5
KPI	10	9	5	15.5	6
Contamination level	10	8	7	15.4	7
Waste classification	9	9	9	15.3	8
Manual input by user	8	10	9	14.8	9
Visualizations and tables	10	7	6	14.7	10
Potential resource	9	8	8	14.6	11
Guaranteed market	10	7	5	14.5	12
Time and location	10	6	5	14	13
Compilations	10	6	4	13.8	14
Automatic matching	8	2	1	8.7	15
Number of transports	7	2	3	8.6	16
Transportation	6	2	3	7.6	17
Landfill disposal	5	2	2	6.4	18
Carbon emissions	3	2	1	4.2	19
Reloading area	3	1	2	3.9	20
Electric vehicles	1	2	4	2.8	21
Buying and selling masses	2	1	1	2.7	22

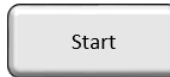
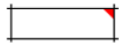
4.2.3 Designing and programming of Masscycle

The front sheet of Masscycle is presented in Figure 4.2. Masscycle was created as a tool in Excel. The different sheets and their purposes are presented in Figure 4.3, where the order of the sheets is indicated by the arrows.

Instructions for use of Masscycle

All white cells should be filled in manually; grey cells are filled in automatically.

Below is an example of what cells containing a comment look like. The red triangle indicates that there is a comment. To view the comment, place the mouse cursor over the cell.



Project specific data

Geographical division: The stretch can be divided into sections or areas. Choose how you want the stretch to be divided by filling in the cells under the appropriate heading. For section division, fill in section start, section end, and section length, and the different sections will be generated in the upcoming sheets. If a specific area/phase is chosen instead, list them in order beneath each other.

Conversion factor: Fill in the conversion factor from cubic meters (m³) to tonnes for all types of materials. This factor will be used to convert volumes from cubic meters to tonnes throughout the tool.

Emerged masses



There are five sheets pertaining to emerged masses. In the first four sheets, the masses generated in the project should be specified and classified. The first four sheets represent four different layers. It is also possible to use these sheets as different work areas (e.g., sheet 1 for drainage, sheet 2 for road ditch materials, etc.). It is not necessary to fill in masses on all four sheets; only fill in when necessary. It is also not required to fill in the same sections in all layers (i.e., it is possible to fill in 3 rows in one layer and 50 rows in another layer). The fifth sheet is a compilation of masses from the various

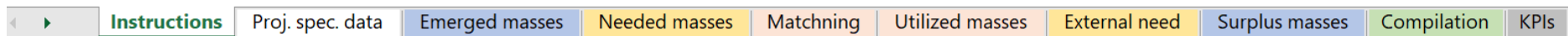


Figure 4.2 Overview of Masscycle.

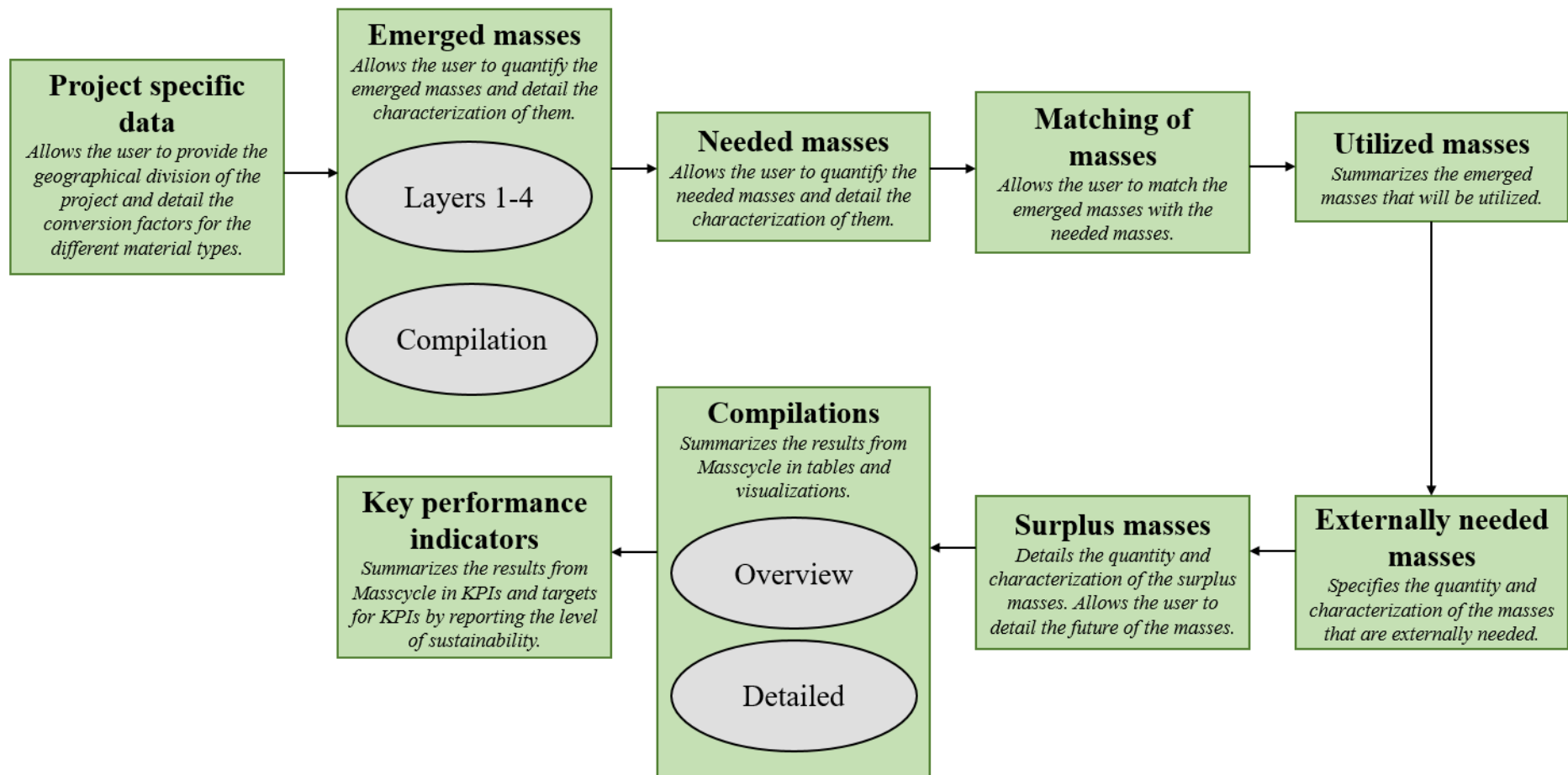


Figure 4.3 Overview of sheets included in Masscycle and their purpose.

To use Masscycle it is necessary to know if the project's geographical location is to be divided according to sections or specific area. For the different material types, one precondition is to know the conversion factors from volume (m³) to weight (tonnes).

There are five sheets for *emerged masses*, which are summarized in Figure 4.4. The first four sheets are the input sheets, where each sheet describes different soil layers. It is not required to fill in all layers, the user only needs to fill in the layers that they find necessary. In these sheets the geographical division of the civil engineering works is automatically included as input from the sheet for project specific data. For each geographical location, the emerged masses are filled in, as well as a classification of the masses' properties. The classification includes the total content (the Swedish Environmental Protection Agency's recommended reference levels for remediation of contaminated land), land area, material type and invasive species. From this classification the user decides whether the masses are appropriate for the project (with or without treatment), or not. The alternatives that the user can fill in for each classification is provided by Masscycle in a dropdown list. If the user has another layer to fill in, a button can be pressed to be moved to the next layer. In the sheet, *emerged masses, compilation*, which is automatically generated, the layers are presented together including all information about the masses. The sheet is filtered to only show the cells where something has been filled in, thus excluding empty layers and sections.

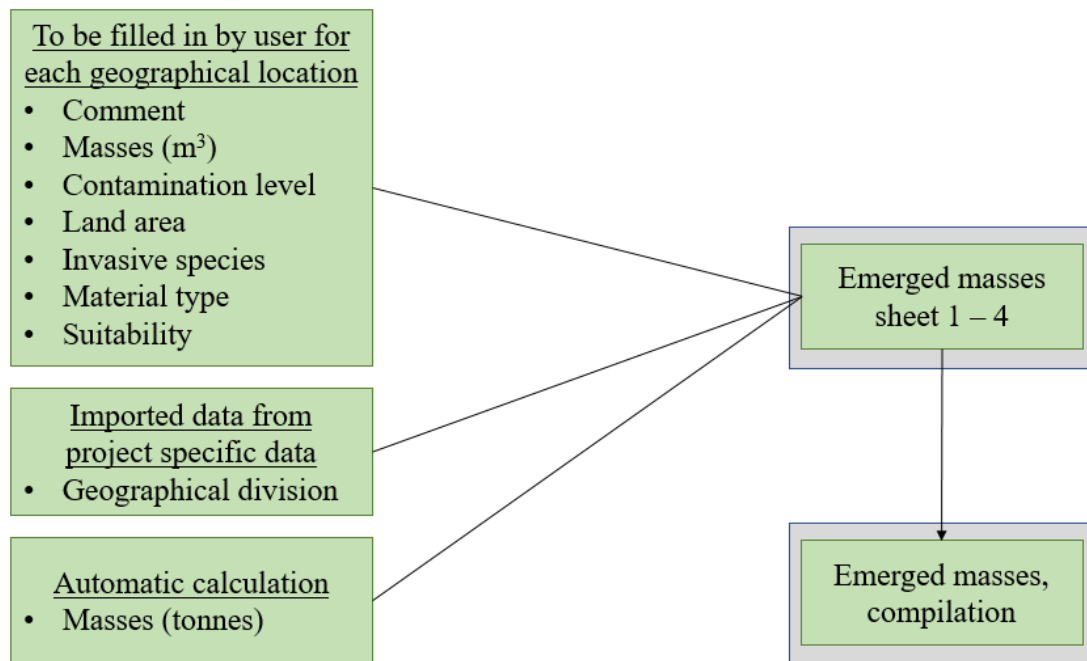


Figure 4.4 Components of the sheets for emerged masses.

In the sheet *needed masses*, there are four different categories that need to be filled in: area with a need i.e., where the masses are needed, construction code according to AMA Anläggning 23, quantity of needed masses in cubic meters and allowed contamination level. The layout of the sheet is presented in Figure 4.5. The allowed contamination level can be filled out as free text as opposed to a dropdown list, allowing the user to be specific in the level of contamination allowed for a specific area. Masscycle will then automatically fill in the description of the construction code and the required

material type. The description of the construction code and the material type are filled in by a connection between an extraction tool of the book AMA Anläggning 23 and Masscycle. Most construction codes allow for several material types to be used and thus one conversion factor cannot be applied and the quantity of needed masses is not converted to tonnes.

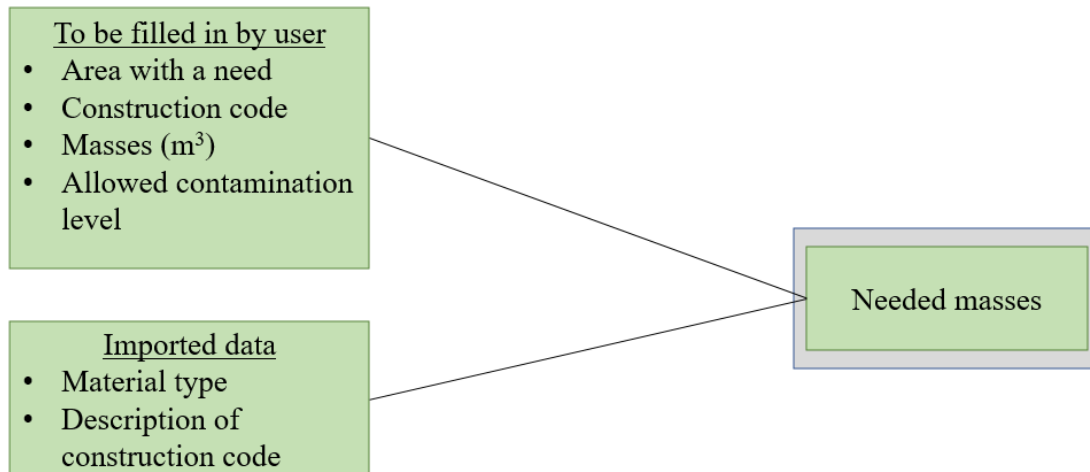


Figure 4.5 Components of the sheet needed masses.

In the sheet *matching of masses*, information from the sheets *needed masses* and *emerged masses, compilation* is included, as seen in Figure 4.6. From *needed masses*, all information is included in *matching of masses*. From *emerged masses, compilation*, all masses that were marked as suitable for the project (with or without treatment) are included. The two extractions from *needed masses* and *emerged masses, compilation*, are placed side by side in *matching of masses*. There is an additional column added, called match code, where the user manually matches the suitable emerged masses to the need of masses. To match the masses the user should study suitable material type, if treatment is needed, total content, land area and invasive species.

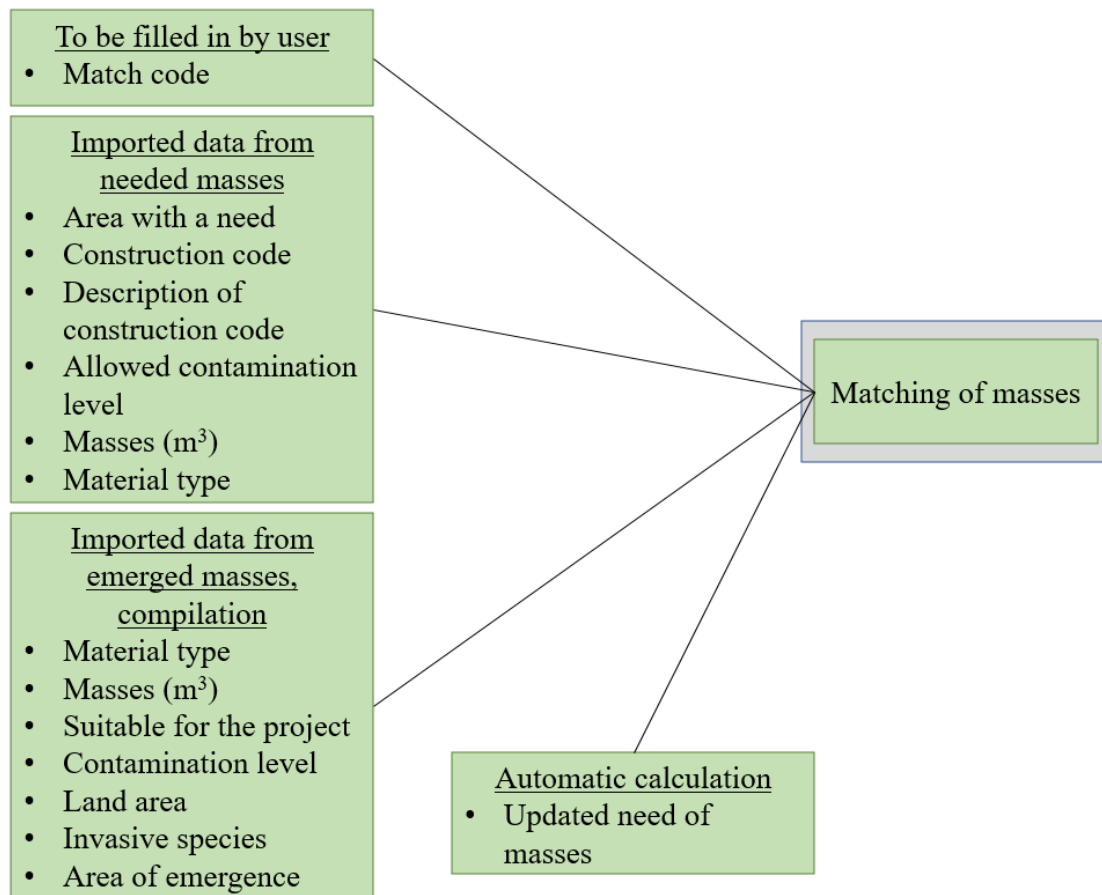


Figure 4.6 Components of the sheet matching of masses.

The sheet for *utilized masses*, is for the most part automatic and presents the results from the *matching of masses*. The properties of the utilized masses are also displayed. In Figure 4.7, the different components in the sheet are specified.

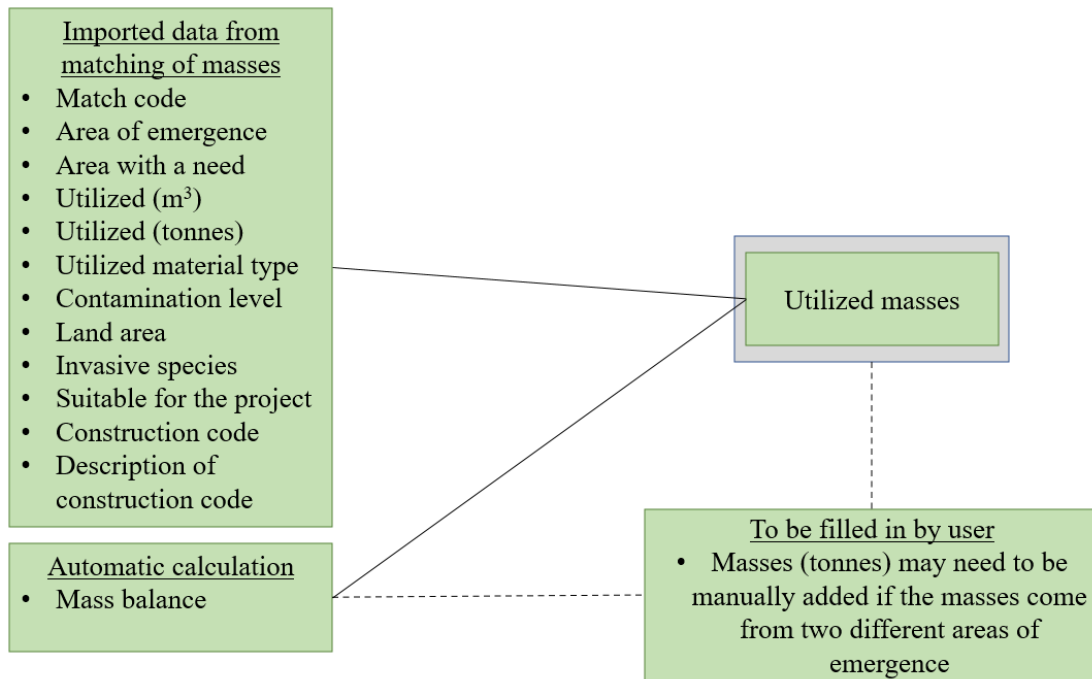


Figure 4.7 Components of the sheet utilized masses.

The sheet for *externally needed masses*, with its components presented in Figure 4.8, is automatically calculated. These masses represent the demand that was not filled by recycled masses from the project.

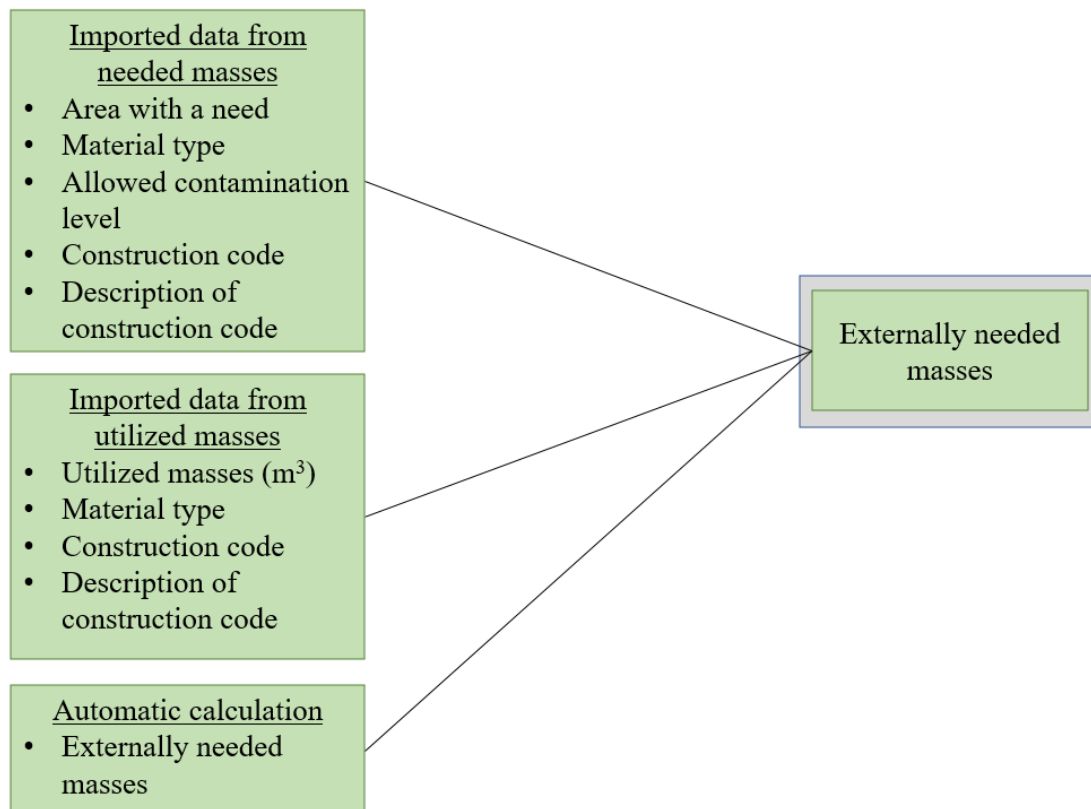


Figure 4.8 Components of the sheet externally needed masses.

The sheet *surplus masses*, includes the masses that were marked as not suitable for the projects, as well as the emerged masses that were marked as suitable, but were not matched with needed masses. All surplus masses are to be classified according to whether they are *resources*, *potential, type 1*, *potential, type 2* or *not resources*. *Potential, type 1* refers to surplus masses (waste) that can be prepared for material recycling (Trafikverket, 2022b). Furthermore, *potential, type 2* refers to surplus masses (waste) that can be used in waste recycling for construction purposes. Masses classified as resources and potential resources are external resources and can be used in other projects. For the masses classified as not a resource, a secondary classification needs to be done. This is a waste classification, consisting of the categories inert, non-hazardous waste and hazardous waste. If the masses are classified as a resource, a second classification needs to be performed, resource classification. In the classification the masses should be classified if they have a contamination level that is more or less than MRR. The different components are specified in Figure 4.9.

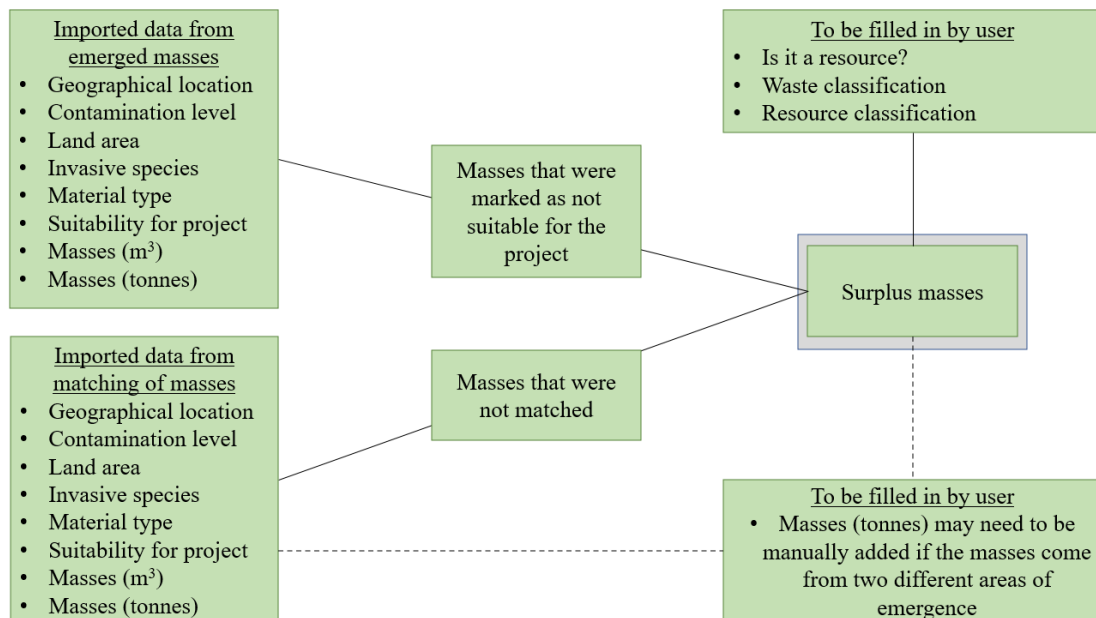


Figure 4.9 Components of the sheet surplus masses.

There are two sheets in Masscycle for compilations, one is more concise and provides an overview of the masses present in the project. The second is more comprehensive and provides visualizations for the previous sheets. The visualizations may need customization by the user by for example changing colour and some probably contain a too large data range thus creating a lot of blank spaces for unused sections and layers. Visualizations in the form of pie charts, sunburst diagrams are used to capture an overview and bar charts are used to include a geographical dimension. Some examples of visualizations are presented in Chapter 4.3.

The last sheet in Masscycle is the sheet for KPIs. The KPIs and targets for KPIs provide the user with information concerning the project's circularity. In total there are 16 KPIs, that concern the masses in the project, disposal sites and economy. The components of the sheet *KPIs* are presented in Figure 4.10.

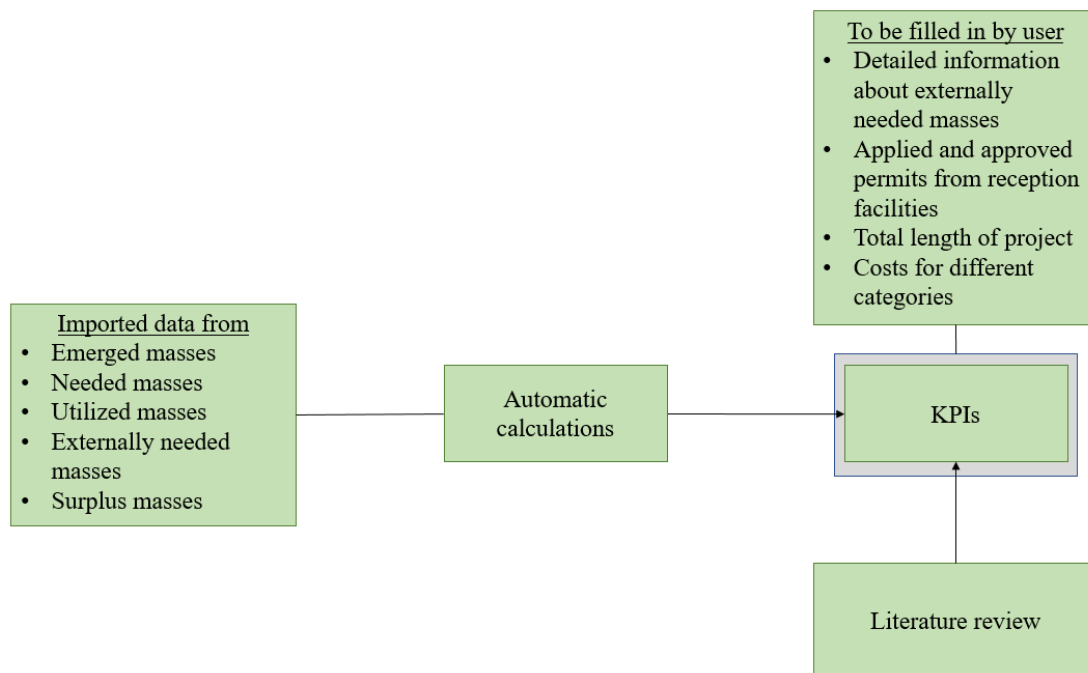


Figure 4.10 Components of the sheet for KPIs.

During the designing and programming phase of Masscycle, several areas of improvements were discovered along the way through reconciliations with employees at the Swedish Transport Administration. Additionally, modifications had to be made from the previous phases as some features did not prove to be useful and some were too difficult to execute. In Table 4.5, the main problems that came up during this phase are presented. How these problems are handled is also presented. More detailed explanations regarding the work executed in this phase is presented in Appendix B.

Table 4.5 Problems that arose during the designing and programming phase, and solutions for them.

Sheet	Problem	Solution
Emerged masses	Different contamination levels at varying depths cannot be specified.	The feature for emerged masses was created as five different sheets: four soil layers and one compilation.
	Creating an understandable and accurate classification of contamination level.	The classifications were determined to be: <ul style="list-style-type: none"> • less than KM • between KM-MKM • more than MKM • less than KM, sulphides • between KM-MKM, sulphides • more than MKM, sulphides

	Leachability may be unknown, as it is only required for when masses are classified as waste.	The leachability classification was moved from the sheet for emerged masses to the sheet for surplus masses (where it is called waste classification).
	It is not possible to specify if the masses are of another type than rock or soil.	This feature was not added as it is not a part of the requirements document.
Needed masses	For some construction codes, there are exceptions to the specified material types.	In the instructions for Masscycle, the user is recommended to double check in AMA Anläggning 23 so that there are not any exceptions for the chosen material type.
	The areas of need might not be the same as the areas of origin.	The user can freely fill out the areas of need.
Matching of masses	Hard to understand how to use sheet.	The instructions suggest factors that are important to consider when performing the matching.
	It is not possible to create an automatic matching of masses.	The sheet was designed to be manual instead of automatic.
	A filter on the column for the material types of emerged masses is needed.	This problem could not be fixed.
Utilized masses	Masscycle does not know which conversion factor that should be used if there are several specified material types.	The user must manually enter the weight of the masses, for such a case.
Compilations	The sheet is not user-friendly as it contains too many visualizations.	Two compilation sheets were created, one more general and one in-depth. Achieving a balance in the number of visualizations, ensuring they are neither overwhelming for users nor inadequate to represent various project scenarios effectively.
	All visualizations could not be automatically created.	A guide on modifying the input data for the diagrams was incorporated into the Masscycle instructions.

4.3 Results from case studies

Table 4.6 presents the answers to the evaluation questions for Project Road 41 and Project B. Some visualizations to present the results of the case studies are presented in Chapter 4.3.1 and 4.3.2. See Appendix D for more visualizations regarding the case studies. Overall, several assumptions had to be made for both projects, as not all data was accessible. In project B, the data was more accessible, since there was a PM Mass Management. The data that was least accessible in both projects was extra input data needed for calculation of the KPIs.

Table 4.6 Answers to evaluation questions for Project Road 41 and Project B.

Evaluation questions	Project Road 41	Project B
Is the input data accessible?	The data was not easily accessible. 24 documents were needed to complete Masscycle. Some data was not obtained through documents, instead through communication with the project manager. There was no PM Mass Management.	The data was semi-accessible. Some simplifications were made where the data was not accessible. There was a PM Mass Management for the project and an Excel file containing information about masses. It was difficult to connect the emerged masses to a specific material type.
What data could not be found?	<ul style="list-style-type: none"> • Conversion factors • Extra data for KPIs • Contamination levels • Allowed contamination level • Characterization of surplus masses 	<ul style="list-style-type: none"> • Conversion factors • Extra data for KPIs • Emerged masses for private roads and public roads other than the highway • Construction codes
What assumptions regarding input data were made?	<ul style="list-style-type: none"> • Conversion factors were assumed according to the literature (Trafikverket, 2022a) • Material types for the masses were estimated using data from boreholes • Masses that were not located by level crossings were virgin, and therefore the lowest classification of contamination was assumed • The quantity of masses at specific locations were estimated for the private roads • Surplus masses were assumed to be <i>not a resource</i> 	<ul style="list-style-type: none"> • Conversion factors were assumed according to literature (Trafikverket, 2022a) • Material types were assumed using PM Mass Management and boreholes, rock masses are assumed to be material type 1, vegetation masses are assumed to be 6A according to boreholes • Construction codes were assumed using the descriptions in the mass management plan • Surplus masses with more useful material types were classified as <i>potential, type 2</i>, while surplus masses with less useful material types were classified as <i>not a resource</i>

4.3.1 Results for project Road 41

The case study on Project Road 41 concluded a relatively low level of resource utilization. The reason for this is because of the contamination level of the masses by the level crossings and the fact that a substantial quantity of masses was of the material type 6A or 6B. According to Svensk Byggtjänst (2023) there are only a few construction codes for material types 6A and 6B. In this project, there is one construction code allowing the use of material type 6A and 6B.

In Figure 4.11, which is an extract from Masscycle, an overview of the masses in the project is presented. As seen in the figure, about 52% of the masses in the project are an internal resource, meaning they emerge from the project and are also utilized within the project. Because of the relatively low level of resource utilization, the need for external masses is high, 89%. In Masscycle, the emerged masses were specified in three different layers because of varying material types and contamination levels with depth. In Figure 4.11, the division of emerged masses between the different layers, as well as the division of needed masses is presented. Of the surplus masses, 100% were classified as not a resource, due to contamination and poor stability.

Figure 4.12 presents a visualization of the emerged masses in the project divided according to their material type and where they emerge. Overall, the most occurring material type is 6B. Figure 4.13 presents a division of the masses according to if they were regarded to be suitable for use in the project, their contamination level and their material type. The majority of the masses were deemed suitable because of their contamination level, but ultimately the need for masses with material type 6B was low, contributing to the low level of resource utilization.

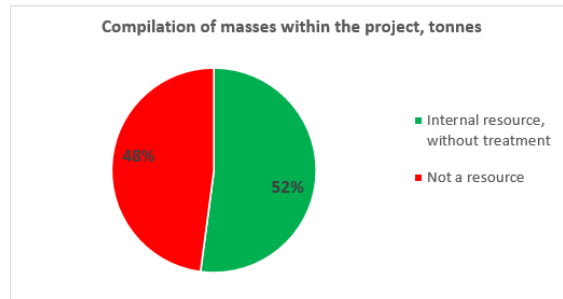
Compilation

Instructions

Next step

Created by: Olivia Jansson & Karolina Olsson

	Emerged masses	Internal resource, without treatment	Internal resource, with treatment	External resource, without treatment	External potential, type 1	External potential, type 2	Not a resource
Masses (m ³)	15 804	7 711	0	0	0	0	8 093
Masses (tonnes)	22 307	11 645	0	0	0	0	10 708



	Emerged masses, layer 1	Emerged masses, layer 2	Emerged masses, layer 3	Emerged masses, layer 4	Total emerged masses	Needed masses	Utilized masses	Externally needed masses	Surplus masses
Masses (m ³)	9 916	4 654	1 234	0	15 804	68 548	7 711	60 837	8 093
Masses (tonnes)	12 658	7 551	2 098	0	22 307		738		10 708

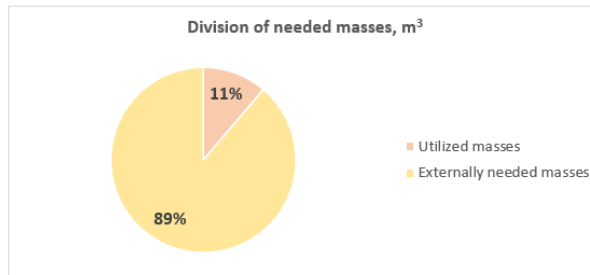


Figure 4.11 Overview of the masses in project Road 41 with quantities for the different categories of masses. The pie charts show that 48% of the emerged masses within the project are not a resource, of the surplus masses, 100% are seen as not a resource and of the masses needed for the project 11% can be fulfilled with emerged masses from within the project.

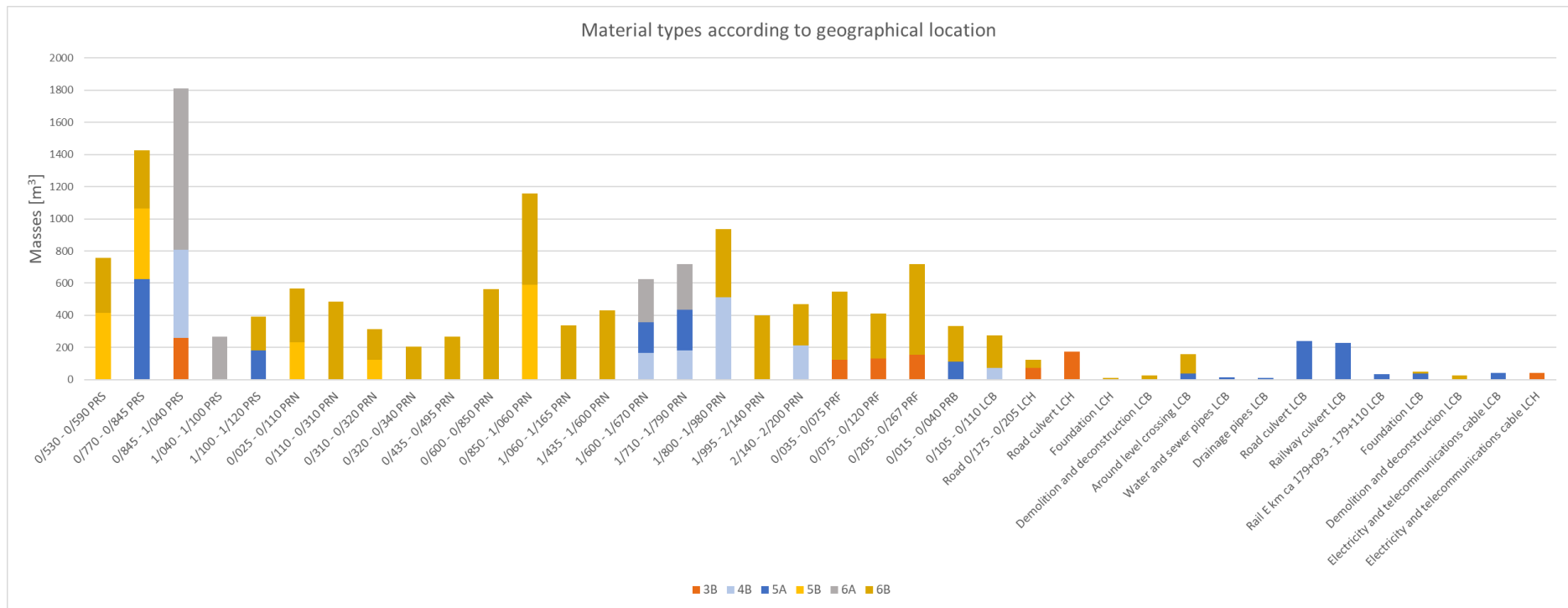


Figure 4.12 Material types of emerged masses in m³ according to geographical location for project Road 41.



Figure 4.13 Division of masses in m³ for project Road 41 according to suitability, contamination level and material type.

The results from scenario 1 are presented in Figures 4.14 and 4.15, where it is clear that the level of contamination is lower than the original case. Scenario 1 resulted in a higher resource utilization, as less masses will be sent to disposal sites. Although there was an increase in internal resources, it was only by 6%. This increase led to a slightly lower need of external masses. In Figure 4.15 it can be observed that all emerged masses were deemed to be suitable for use in the project. The masses with material type 6A and 6B make up more than half of the masses in the project and the need for masses with material type 6A and 6B is low. The small increase in resource utilization for scenario 1 is because of the reclassification of contamination level amongst masses with material type 3B.

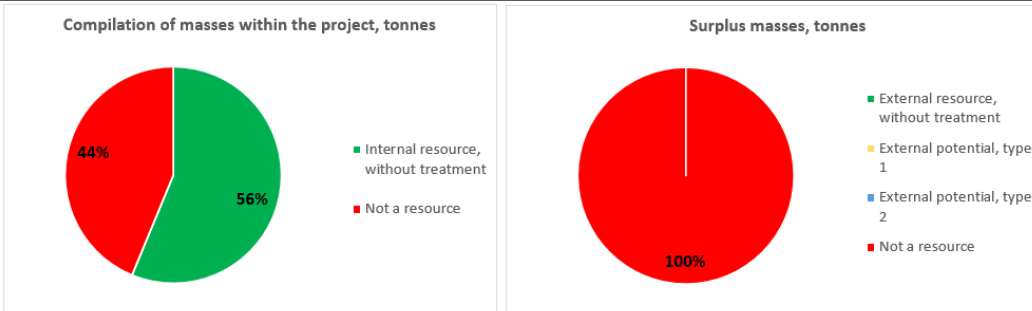
Compilation, Scenario 1

Instructions

Next step

Created by: Olivia Jansson & Karolina Olsson

	Emerged masses	Internal resource, without treatment	Internal resource, with treatment	External resource, without treatment	External potential, type 1	External potential, type 2	Not a resource
Masses (m ³)	15 804	8 291	0	0	0	0	7 513
Masses (tonnes)	22 307	12 487	0	0	0	0	9 712



	Emerged masses, layer 1	Emerged masses, layer 2	Emerged masses, layer 3	Emerged masses, layer 4	Total emerged masses	Needed masses	Utilized masses	Externally needed masses	Surplus masses
Masses (m ³)	9 916	4 654	1 234	0	15 804	68 548	8 291	60 257	7 513
Masses (tonnes)	12 658	7 551	2 098	0	22 307		12 487		9 712

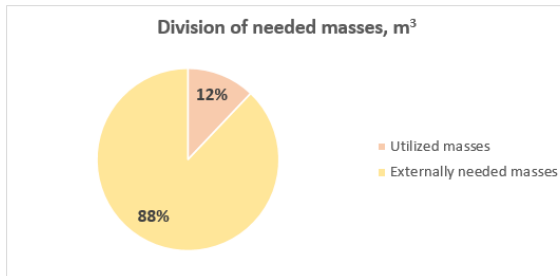


Figure 4.14 Overview of the masses in project Road 41, Scenario 1, with quantities for the different categories of masses. The pie charts show that 44% of the emerged masses within the project are not a resource, of the surplus masses, 100% are seen as not a resource and of the masses needed for the project 12% can be fulfilled with emerged masses from within the project.

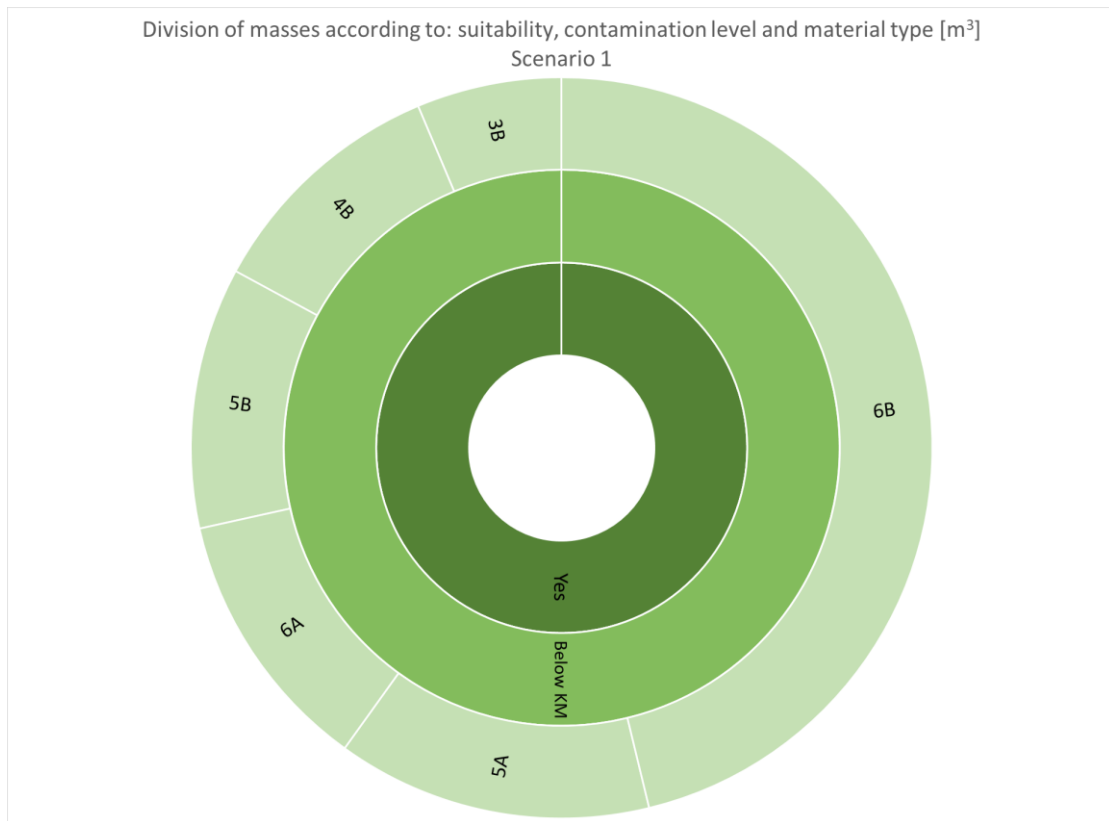


Figure 4.15 Division of masses in m³ for project Road 41, scenario 1, according to suitability, contamination level and material type.

The results from scenario 2 are presented in Figures 4.16 and 4.17. In Figure 4.16 it can be seen that 46% of the emerged masses are an internal resource, which is a decrease from the original case, where 52% of the emerged masses were an internal resource. In scenario 2 there is an increased need for external masses to the project, approximately 2 000 m³. This is due to the change of material type 5A to 6A, since material type 5A can be utilized for more construction codes. Figure 4.17 presents a division of the masses according to if they were regarded to be suitable for use in the project, their contamination level and their material type, where it is clear that there has been an increase of masses with the material types 6A and 6B.

Compilation, Scenario 2

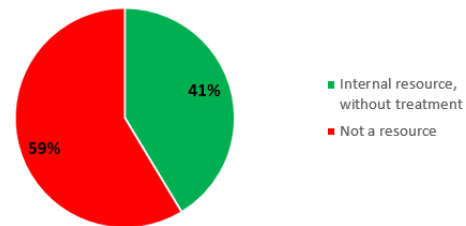
Instructions

Next step

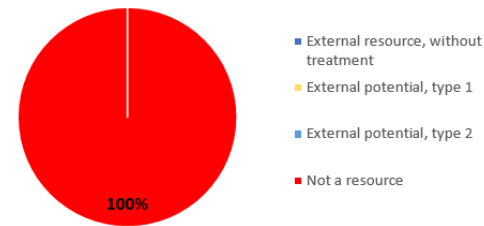
Created by: Olivia Jansson & Karolina Olsson

	Emerged masses	Internal resource, without treatment	Internal resource, with treatment	External resource, without treatment	External potential, type 1	External potential, type 2	Not a resource
Masses (m ³)	15 804	6 030	0	0	0	0	9 774
Masses (tonnes)	26 298	8 643	0	0	0	0	12 256

Compilation of masses within the project, tonnes



Surplus masses, tonnes



	Emerged masses, layer 1	Emerged masses, layer 2	Emerged masses, layer 3	Emerged masses, layer 4	Total emerged masses	Needed masses	Utilized masses	Externally needed masses	Surplus masses
Masses (m ³)	9 916	4 654	1 234	0	15 804	68 548	6 030	62 518	9 774
Masses (tonnes)	17 670	6 717	1 910	0	26 298		8 643		12 256

Division of needed masses, m³

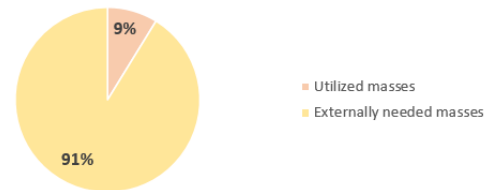


Figure 4.16 Overview of the masses in project Road 41, Scenario 2, with quantities for the different categories of masses. The pie charts show that 59% of the emerged masses within the project are not a resource, of the surplus masses, 100% are seen as not a resource and of the masses needed for the project 9% can be fulfilled with emerged masses from within the project.

Division of masses according to: suitability, contamination level and material type [m³]
Scenario 2

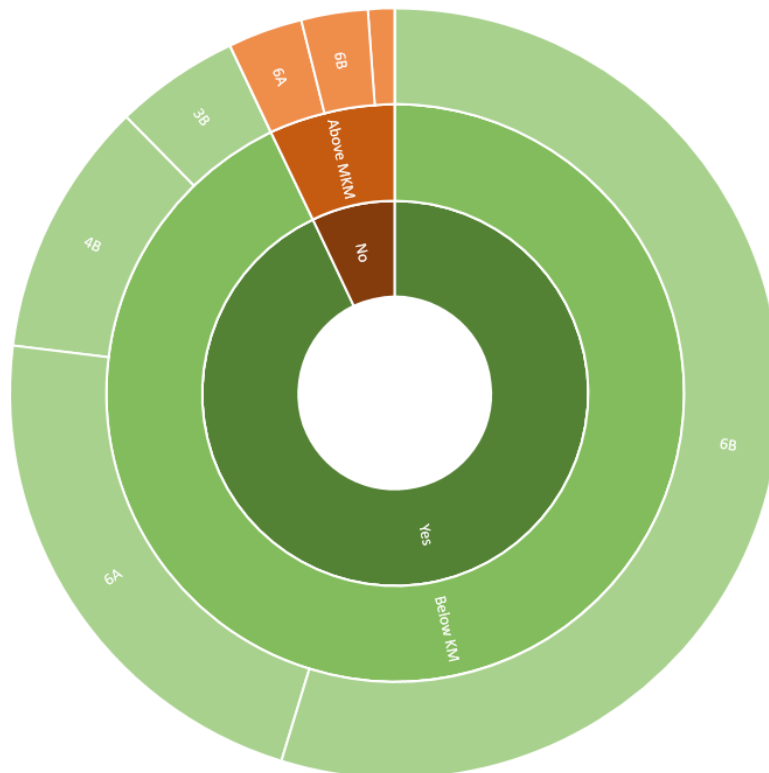


Figure 4.17 Division of masses in m³ for project Road 41, scenario 2, according to suitability, contamination level and material type.

Additional data required in the sheet for KPIs could not be found, and thus all results for KPIs were not obtained. Additionally, there was no requirement for coordination of masses between projects. The obtained results for KPIs are displayed in Figure 4.18. None of the results for KPIs reach their target value. Scenario 1 overall rendered results closer to the targets for the KPIs than scenario 2 and the original case.

Key performance indicators

Created by: Olivia Jansson & Karolina Olsson

Key performance indicator	Target for KPI	Current value	Scenario 1	Scenario 2
The relation between externally needed masses in m ³ and total needed masses in m ³	0%	89%	88%	91%
The relation between recycled masses (internally and externally) in tonnes and emerged masses in tonnes	100%	40%	56%	28%
The relation between internal resources in tonnes and masses identified as suitable for the project in tonnes	100%	43%	56%	30%
The relation between internal resources in m ³ and total needed masses in m ³	100%	11%	12%	9%
The relation between masses that been met by recycled masses in m ³ (from within the project or from external projects) and total needed masses in m ³	100%	11%	12%	9%
The relation between total recycled masses in tonnes within the project and recycled masses that needed treatment in tonnes		0%	0%	0%
The relation between virgin masses from quarry in m ³ and total needed masses in m ³	0%	89%	88%	91%

Figure 4.18 KPI and target for KPI for project Road 41 and its scenarios.

The project manager for Road 41, J. Edelberg stated that he was very satisfied with the results from Masscycle and said that the results were very useful and seemed accurate (personal communication, March 19, 2024). Further he mentioned that the results would be used during construction to ensure that the masses are utilized as much as possible. Edelberg also communicated that the assumptions that were made were reasonable. Regarding the scenarios, he stated that the first scenario is unlikely to occur, but the second scenario is partially likely to occur. He mentioned that it is possible that more masses with material type 6A and 6B will emerge than initially predicted. Therefore, the results from scenario 2 were of interest. Further, Edelberg emphasized the interest for follow-up. He mentioned that he would consider updating input data in Masscycle to see the difference in outcome and observe how the KPIs changed. Regarding the visualizations that were presented to Edelberg, he said that they displayed the masses in the project in a way that is easy to understand and that they help create an overall understanding of specific problem areas within the project.

4.3.2 Results for project B

There was a high resource utilization in project B. This was due to unexploited land with low contamination levels as well as overall good stability in the area, resulting in the emerging masses having the material types that were needed in the project. A compilation of the results for the original case of project B is presented in Figure 4.19. 98% of the emerged masses in the project are an internal resource. There is a surplus of

approximately 18 000 m³ of which 39% is not a resource and 61% is a potential resource, type 2. Of the total need for masses, 18% is needs to be externally sourced. Figure 4.20 presents a division of the emerged masses according to material type and geographical location. There are rock masses (material types 1 and 2) along the entire stretch. In Figure 4.21 the contamination level for the emerged masses in project B is presented, where it can be seen that 99.6% of the masses are below KM. The remaining 0.4% of the emerged masses were determined to be between KM-MKM.

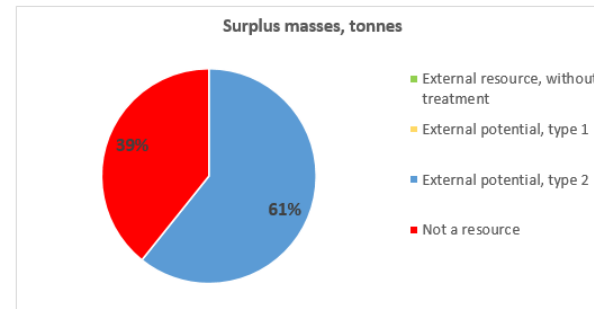
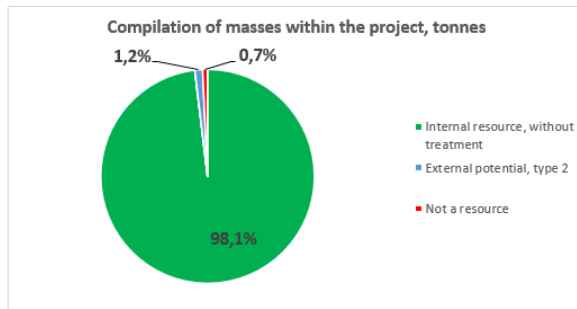
Compilation

Instructions

Next step

Created by: Olivia Jansson & Karolina Olsson

	Emerged masses	Internal resource, without treatment	Internal resource, with treatment	External resource, without treatment	External potential, type 1	External potential, type 2	Not a resource
Masses (m ³)	814 252	796 666	0	0	0	9 853	7 732
Masses (tonnes)	1 446 065	1 420 541	0	0	0	16 751	10 825



	Emerged masses, layer 1	Emerged masses, layer 2	Emerged masses, layer 3	Emerged masses, layer 4	Total emerged masses	Needed masses	Utilized masses	Externally needed masses	Surplus masses
Masses (m ³)	120 208	132 721	350 289	211 033	814 252	969 484	796 666	172 818	17 586
Masses (tonnes)	168 291	225 626	630 082	422 066	1 446 065		1 420 541		27 576

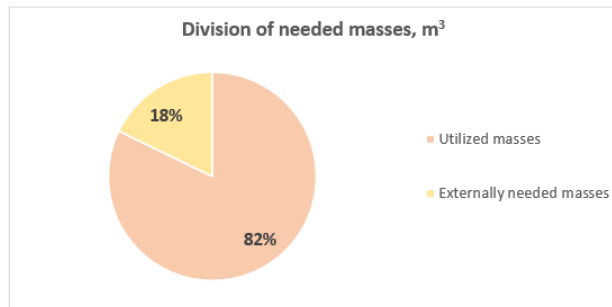


Figure 4.19 Compilation of results for project B.

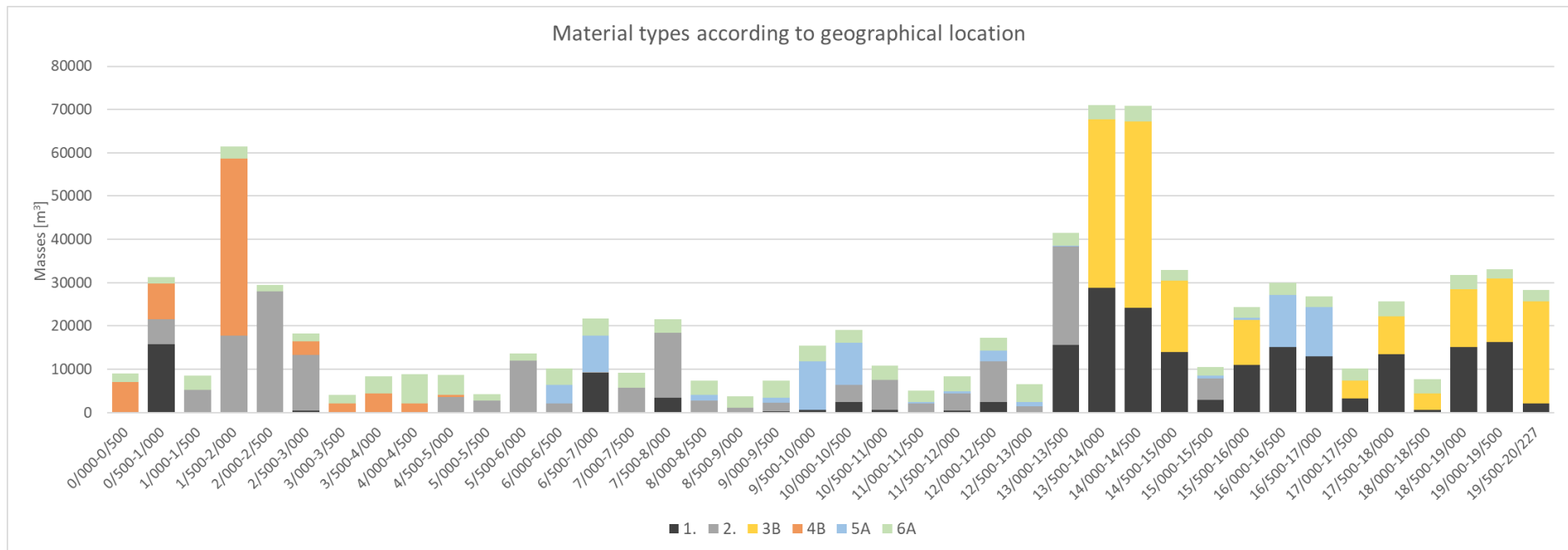


Figure 4.20 Quantity of masses in m³ for project B according to material type and geographical location.

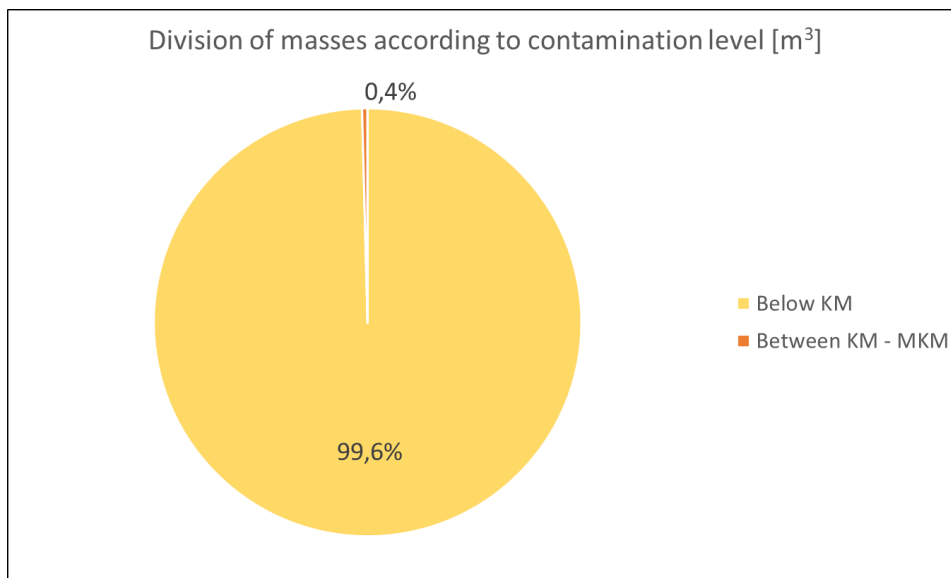


Figure 4.21 Division of masses in m³ for project B according to contamination level.

The results from scenario 1 are presented in Figures 4.22 and 4.23. Scenario 1 resulted in an even higher resource utilization (91%), than the original case for project B, and thus has a lower need for external masses of only 9%. Almost 100% of the emerged masses were internal resources. The surplus masses, that consisted of 0.02% of the emerged masses were considered to not be a resource, because of the small quantity and them being vegetation masses. Scenario 1 was created to provide a positive perspective, where a larger quantity of masses has more useful material types, which can be seen in Figure 4.23. Useful material types refer to those most common in construction codes. In comparison to the original case, the masses with material types 3B and 5A were changed to 2 and 4B respectively.

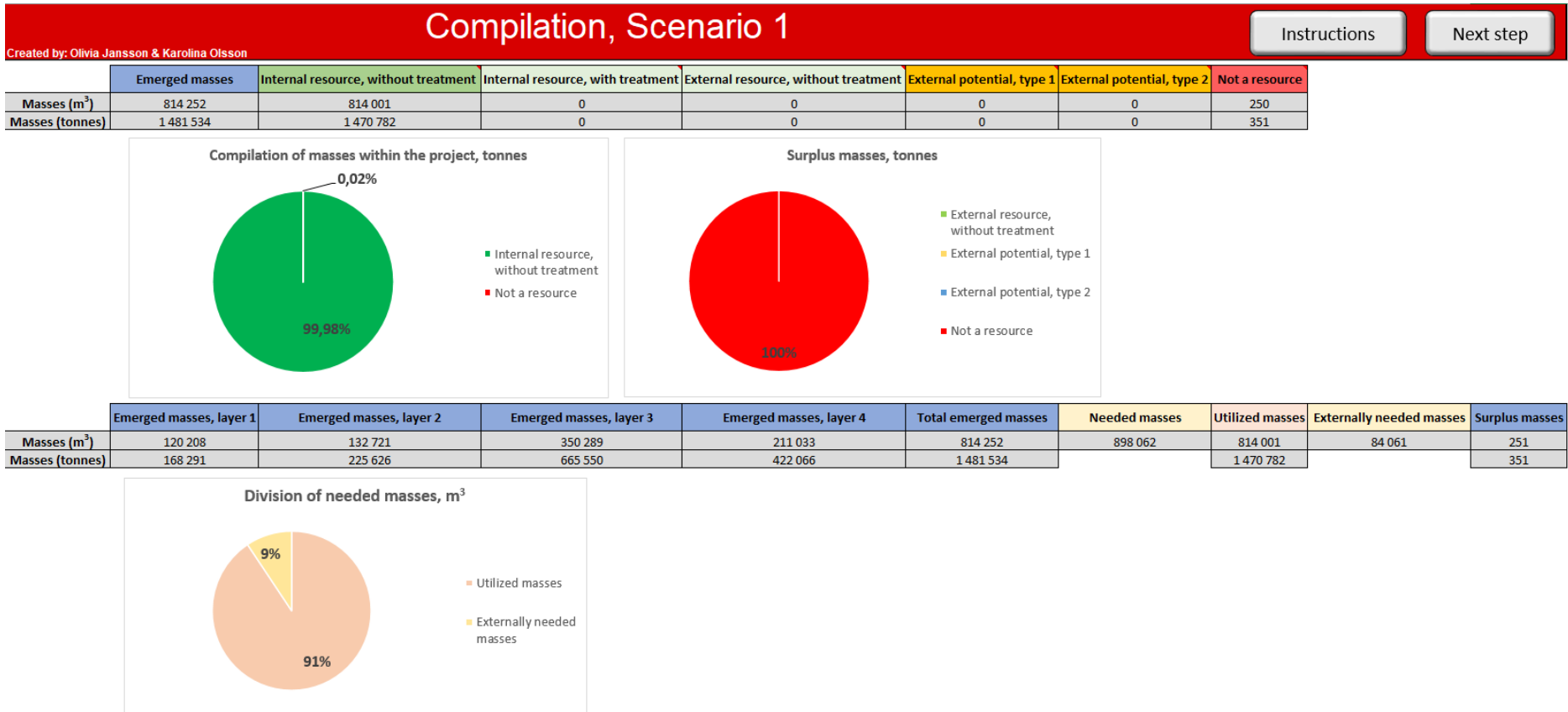


Figure 4.22 Compilation of results for project B, scenario 1.

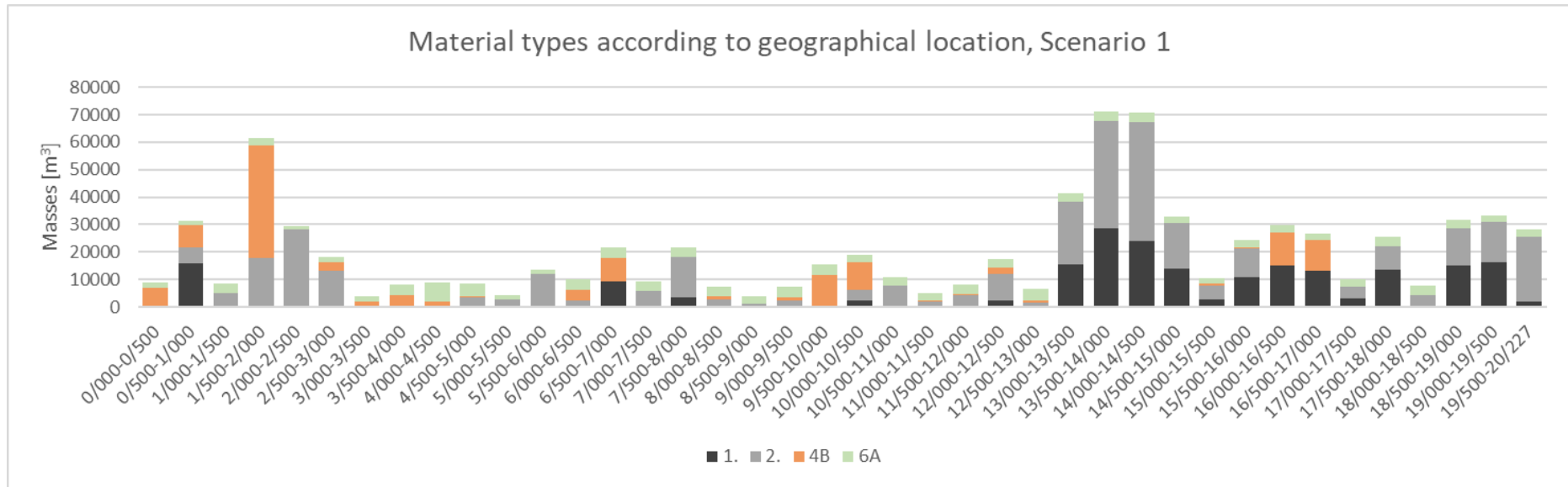


Figure 4.23 Quantity of masses in m³ according to material type and geographical location for project B, scenario 1.

Scenario 2 resulted in a lower resource utilization than both the original case and scenario 1, which can be observed in Figure 4.24. The need for external masses is therefore also higher. Figure 4.25 presents the division of emerged masses according to material type and location. In the second scenario 43% of the masses are material type 3B. The need for masses of material type 3B is low in this project, which results in a large surplus. Since the masses have a low contamination level, it would be possible that other projects in the vicinity would be interested in the masses. Therefore, the surplus of 3B masses was classified as *potential, type 2*. There are 250 m³ of surplus masses that have been classified as not a resource, these masses are of material type 6A.

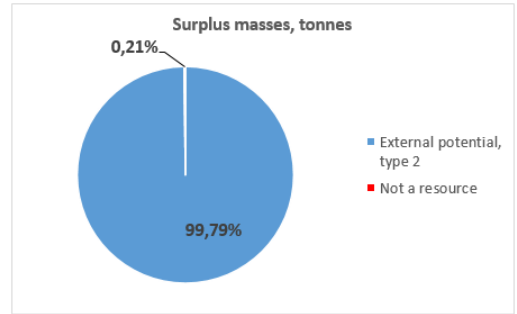
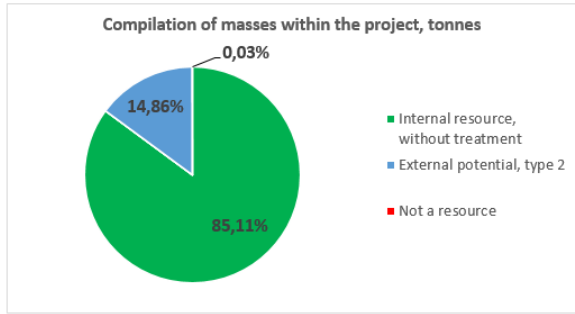
Compilation, Scenario 2

Instructions

Next step

Created by: Olivia Jansson & Karolina Olsson

	Emerged masses	Internal resource, without treatment	Internal resource, with treatment	External resource, without treatment	External potential, type 1	External potential, type 2	Not a resource
Masses (m ³)	814 252	692 164	0	0	0	121 836	250
Masses (tonnes)	1 411 476	1 185 887	0	0	0	207 121	426



	Emerged masses, layer 1	Emerged masses, layer 2	Emerged masses, layer 3	Emerged masses, layer 4	Total emerged masses	Needed masses	Utilized masses	Externally needed masses	Surplus masses
Masses (m ³)	120 208	132 721	350 289	211 033	814 252	1 038 132	692 164	345 968	122 087
Masses (tonnes)	168 291	225 626	595 492	422 066	1 411 476		1 185 887		207 547

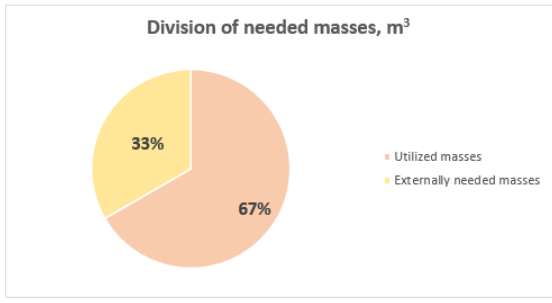


Figure 4.24 Compilation of results for project B, scenario 2.

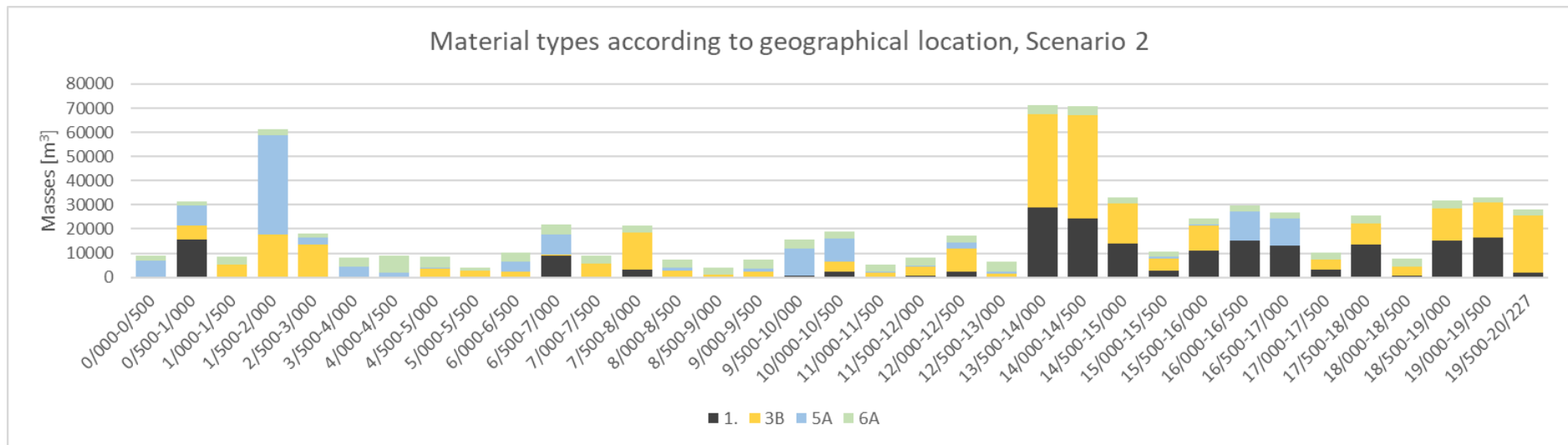


Figure 4.25 Quantity of masses in m³ according to material type and geographical location for project B, scenario 2.

It was not possible to obtain all results for the KPIs, since additional data required in the sheet for KPIs could not be found. In Figure 4.26 the results for KPIs from the original case, scenario 1 and scenario 2 are presented. Overall, the KPIs prove that project B is a circular project. The difference in results for KPIs for scenario 1 compared to the original case is relatively small, while for scenario 2 there is a clear change in all results for KPIs.

Key performance indicators

Created by: Olivia Jansson & Karolina Olsson

Key performance indicators	Target for KPI	Current value	Scenario 1	Scenario 2
The relation between externally needed masses in m ³ and total needed masses in m ³	0%	18%	9%	33%
The relation between recycled masses (internally and externally) in tonnes and emerged masses in tonnes	100%	98%	99%	84%
The relation between internal resources in tonnes and masses identified as suitable for the project in tonnes	100%	98%	99%	84%
The relation between internal resources in m ³ and total needed masses in m ³	100%	82%	91%	67%
The relation between masses that been met by recycled masses in m ³ (from within the project or from external projects) and total needed masses in m ³	100%	82%	91%	67%
The relation between total recycled masses in tonnes within the project and recycled masses that needed treatment in tonnes		0%	0%	0%
The relation between virgin masses from quarry in m ³ and total needed masses in m ³	0%	18%	9%	33%

Figure 4.26 KPIs and targets for KPIs for project B, scenarios 1 and 2.

When presenting the results from Masscycle for the project team for project B, the response was positive. It was mentioned that the results from Masscycle better fulfilled the requirements document than the PM Mass Management. The chosen scenarios were not likely to occur, but their results together with the original case were beneficial to understand the span that the resource utilization may lie within. In addition to the presented scenarios, it was suggested that adjusting the depth of the rock would be a good scenario, because there were uncertainties in the rock models due to extrapolations. Additional scenarios were not performed due to time limitations. An improvement that was suggested was to study the specific quantity of masses needed for different locations when performing the matching of masses, to ensure that the distances between the areas of emergence and need were not too far from each other. To be able to complete this, more data would need to have been provided in the PM Mass Management for project B. It only contains the quantity of needed masses and not what material types that are needed at different locations. Because of this it is not possible to perform a more specific matching.

5 Discussion

5.1 Implementation of KPIs

In the literature, several KPIs and targets for KPIs were identified as being connected to the planning of mass management within infrastructure projects. While some KPIs and targets for KPIs were easily integrated into Masscycle, others required adjustments to align with the input parameters of the tool. In a few instances, small input tables were introduced, allowing users to provide additional information for obtaining results from specific KPIs, for example KPI 1 and KPI 10. However, several KPIs identified in the literature review were excluded from Masscycle, some because they yielded overly vague results and others because they required an extensive amount of new information that would be challenging for users to provide.

In Table 4.3 different KPIs are described within KPI 1 regarding project cost per tonne emerged/waste/recycled masses, through reconciliation with a project manager it was stated that a combination of these KPIs would be more useful. Therefore, they were combined into *Mass management cost per meter of project*.

KPI 11 was changed from the *Share of total project cost that is the sampling cost* to the *Share of total project cost that is the total mass management cost*. This change was done since it is more relevant considering the aim of the tool. KPIs 20–28 were deemed to be too vague to use or too difficult to measure.

KPI 3, *The share of total required masses for the project, which have been met with recycled masses or surplus masses from within the project or from external projects*, uses terminology that does not align with the terminology used in this thesis and was therefore changed. According to Cullhed et al. (2023), masses that are utilized within the same project are never surplus masses. The two KPIs developed based on KPI 3 were adapted to this terminology, with one focusing on resources within the project and the other encompassing recycled masses from both within the project and from other projects.

The alteration of KPI 14, *The share of emerged masses which meet the technical requirements and have been recycled, on site or off site*, was necessary as Masscycle relies on user assessments to compare the technical requirements in the project to the properties of the masses. Besides the technical requirements there are also environmental requirements, which the user needs to assess in Masscycle. Masscycle is incapable of automatically distinguishing between technical and environmental requirements.

For KPI 13b, *Relation between externally needed masses in m^3 and total needed masses in m^3* , it is essential to note that if the KPI was to assess circularity from a broader perspective, a target of 0% might not be suitable. A broader perspective refers to a perspective that considers more than the specific project, for example, all of the Swedish Transport Administration's projects or a societal perspective. Optimal circularity might involve transporting masses of a particular quality to another project rather than using them on-site (Andersson-Sköld et al., 2022). This could be the case, for instance, if the emerged masses within an infrastructure project contain a lower ball mill value than required for the project. Instead of using the masses as fill material for

that project, they would be more valuable for another project in need of masses with a low ball mill value. Consequently, the user is required to determine the target for the KPI based on project-specific considerations.

Presenting KPIs is not a part of the requirements document. Therefore, it is possible that the automatically calculated KPIs will be overlooked, and the KPIs requiring extra input data will not be completed. A solution for this would be that the project manager sees a benefit in using the KPIs and sets it as a requirement. Alternatively, the demand of presenting of KPIs should be added as a part of the requirements document. Upon discussions with employees at the Swedish Transport Administration, some lifted that including KPIs in Masscycle was a good idea as they provide an overview of the project. During reconciliations with employees, it was mentioned that KPIs could be used on a higher level when for example comparing projects to each other or to compile several projects carried out within a certain timespan. If further development to the KPIs is needed for this purpose, it is recommended to be analysed as further research.

An evaluation that needed to be done was choosing whether or not to include targets for the KPIs. The advantage of providing a target was to provide the projects using Masscycle with a goal and an understanding of if the results are positive or negative. A disadvantage of providing a target for the KPIs is that they may not be accurate for the project, and instead it might be better for them to set their own targets. Targets for KPIs in Masscycle were implemented but the cells in Excel, providing them will not be locked and thereby it is possible to change values if they are inappropriate for the project.

Upon testing Masscycle on different road infrastructure projects, the result values for the KPIs were evaluated. For both infrastructure projects, the input data was insufficient to receive result values for all KPIs. The input data needed regarding disposal sites was not available at the Swedish Transport Administration and instead decided by the contractor or planned by the consultant. These KPIs were still considered important to include in Masscycle, as consultants using Masscycle may be able to fill it out and because it is connected to the demands in the requirements document. Regarding costs for the project and mass management, projected costs were established for both evaluated projects, but not available for sharing. The costs for sampling were not available for the two projects. This is because the sampling was carried out by several different consultancy firms, and some samplings took place many years ago. It is reasonable to assume that this cost will be available at consultancy firms for other projects.

5.2 Findings from case studies

The main reason that the case studies were performed was to ensure that using Masscycle would yield a positive contribution to the project and that there were no errors hindering the different functions in the program. During the development of a tool, it is hard to discover all errors which is why two case studies were performed. By testing the tool on two projects and analysing the results, most errors were likely discovered and subsequently fixed. Due to the tool's extensive nature, there may be errors that have not been discovered. These errors could either hinder a function or produce an incorrect result. The errors that hinder a function are easier to spot since an

error message or empty cell/ visualization will show. Errors producing incorrect results are harder to identify as they may be small and do not generate an error message.

Overall, the data extraction for the two projects was time consuming. A reason for this was not knowing where to find specific data required for Masscycle. It would be beneficial to have project experience when working with Masscycle, partly to understand if results are reasonable and partly to make decisions in the program, for example when matching the emerged masses with the needed masses. Without prior project knowledge it is hard to know what is feasible. It is highly possible that data extraction would be less time consuming if the projects at the beginning of the project planning, knew that Masscycle was going to be performed.

In Project B, there was an uncertainty regarding the material types of the emerged masses. From the Excel-file corresponding to the PM Mass Management, the material types were presented as two groups for soil masses, either 2 and 3B or 4 and 5. In another document, the documentation of drillings along the planned highway provided information about the material types. It was not possible to assign the material types from the boreholes to different quantities of masses without large estimations. Therefore, it was deemed that using the material type groups and the original data from the Excel-file would yield the most accurate results.

Another uncertainty in project B concerned the masses from the private roads and the public roads other than the highway. The needed masses were presented in both PM Mass Management and the provided Excel-file. In PM Mass Management the masses were presented in a table, where they were divided according to the description of the construction code, whereas in the Excel-file the needed masses were divided according to road sections. Since the construction codes provide material types, which is an important part of how the matching is done in Masscycle, the quantities of needed masses from PM Mass Management were imported to Masscycle. One problem with the table was that the needed masses were not divided according to if they were needed for the highway, or other public and private roads. As a result, the emerged masses only come from the highway construction and needed masses represent the whole project, which causes a slight fault in the results. In the PM Mass Management, it is stated that the quantity of the needed masses can be adjusted to match the quantity of emerged masses. A possible adjustment is a change that will not affect the functionality of the civil engineering work, such as increasing the need of masses for filling of slopes. These types of adjustments were made in Masscycle for Project B, by slightly increasing the need of certain material types, which led to a higher resource utilization.

5.3 Uncertainties and their effects on Masscycle

The estimation of different soil parameters is done through sampling. Both the contamination level of masses and the technical parameters are assessed in this manner. There is a risk that uncertainties occur from the sampling when estimating different soil properties, due to for example the sampling target (Ramsey et al., 2019). The definition of a sampling target is a specific location with soil properties that the sample is intended to represent. If a sample is intended to represent a specific location but happens to be an outlier, large uncertainties of the input parameters to Masscycle occur. Therefore, a recommendation for further work is an implementation of a function that can assess uncertainties of input parameters.

Besides the uncertainties of the input data to Masscycle, the manual assessments by the user also introduces uncertainties through subjectivity. The aspects of the tool particularly susceptible to subjectivity include assessing the suitability of masses for the project (in the sheet *emerged masses*) and the matching of the emerged masses with the needed masses. This susceptibility can lead to two possible outcomes. If the user adopts a lenient approach, Masscycle is likely to present a favourable result with KPIs closely aligned with their targets. Conversely, a strict user approach may yield less favourable results and KPIs further from their targets. Finding the right balance in the planning phase is crucial, as being too strict or too lenient can have significant consequences in the construction phase. A lenient approach may result in a false favourable result whereas a strict approach may result in a false unfavourable result.

A false favourable result (through a lenient approach) could lead to an unexpected surplus of masses that need to be handled, resulting in escalating project costs. Conversely, a false unfavourable result (through a strict approach) could lead to recognising that the initial classification of the masses as unsuitable is incorrect. This recognition of resources during the construction phase as opposed to during the planning phase may lead to a missed opportunity of optimizing the masses. Dealing with masses classified in the construction phase as a resource may pose as a challenge, such as if there is no longer an area with a need or if it conflicts with the project schedule.

Throughout the project, the only stakeholders that were engaged were employees at the Swedish Transport Administration. It is difficult to know if this had positive or negative consequences. The reason for the sole engagement of the Swedish Transport Administration was that it is for them that Masscycle will be completed and thus they should be the ones to judge what results they want. By engaging other stakeholders, it is possible that the tool would be developed in a similar manner that consultants are working with mass management and how they produce the PM Mass Managements, which the Swedish Transport Administration are not satisfied with today.

There are several aspects of circularity of an infrastructure project and mass management that are not included in Masscycle. To exemplify, transportation and carbon emissions are not included in the tool. This results in a partially subjective image of the circularity of a project. These topics were included in the needs analysis, but were ranked low in the prioritization due to the difficulty of programming/designing such functionalities and the expected time consumption in implementing them. The inclusion of carbon emissions was also scored low in the level of importance, since it is not a demand in the requirements document. Additionally, the Swedish Transport Administration uses Klimatkalkyl for estimating the climate impact of civil engineering works (Toller, 2020).

5.4 Excel-based or web-based

Through discussions with employees at the Swedish Transport Administration, the question arose regarding if Masscycle should take the form of an Excel tool or a web-based application. The consensus among most employees was an Excel-based solution, due to their familiarity with the program. However, one individual expressed a preference for a web-based platform.

A notable advantage of a web-based tool lies in its capacity to facilitate simultaneous collaboration among multiple users, a functionality not supported within the Swedish Transport Administration's current Excel-editing framework. Additionally, a web-based tool offers greater flexibility for feature development compared to Excel, which has inherent limitations. For instance, a web-based tool can incorporate more of the demands from the requirements document. This might involve creating distinct steps, some mirroring Masscycle's functionality, while others instruct users to evaluate various project components and analyse maps. Ultimately, such a tool could combine these diverse elements to generate a comprehensive PM Mass Management. Another potential benefit of a web-based tool is the ability to store past results, enabling a return of experience to enhance circular mass management for future projects.

On the other hand, advantages with creating an Excel-based tool include the experience that employees at the Swedish Transport Administration have using Excel. Shifting to a web-based platform would mean that users need to learn a new program, which could potentially discourage them from adopting the tool. Given the strong preference for Excel expressed by the majority of employees and the familiarity with Excel, it became clear that an Excel-based approach would deliver the best results. Future considerations for transitioning Masscycle to a web-based tool could be explored if its usage indicates a need for further development in that direction.

5.5 Implementation of Masscycle at the Swedish Transport Administration

During different reconciliations with employees within mass management at the Swedish Transport Administration, it was said that a tool like Masscycle is essential for a future regional mass management planning tool, as information about masses in projects would be input data for such a tool. Furthermore, several employees stated that a tool such as Masscycle is needed and the results from it can lead to more circular project planning. Moreover, in an interview conducted by Andersson-Sköld et al. (2022) the need for a tool or template to satisfy the Swedish Transport Administration's demands was mentioned. According to the Swedish Environmental Protection Agency, a regional mass management planning tool capable of matching supply and demand of masses is needed (Naturvårdsverket, 2022). The tool created for this thesis is not a regional mass management planning tool but a project mass management planning tool, which contains parts of what the Swedish Environmental Protection Agency requests, where the generated results can serve as input data for a regional tool.

In Norway, the usage of the tool VegLCA is mandatory for all road and railway infrastructure projects over 51 million Norwegian kroner (Statens Vegvesen, n.d). Creating a tool that is mandatory, necessitates ongoing updates to ensure a properly working tool. Overall, to make sure that the tool is used, it is important that it works correctly without errors. Masscycle, while not mandatory, simplifies the process of meeting the demands in the requirements document. To maximize the number of projects that comply with the requirements document, it is reasonable to consider making the use of Masscycle compulsory. This can be done through including Masscycle in the requirements document for mass management or in the procurements.

Before the process of implementation of Masscycle at the Swedish Transport Administration is to begin, the tool should go through additional testing. Ideally, the

tool should be tested on more road infrastructure projects and by users that are not the developers. By others testing the tool, ease of use could be further evaluated. A pilot project, where it is mandatory for the contractor to apply Masscycle during the project planning of mass management is scheduled to start in the autumn of 2024 (J. Edelberg, personal communication, November 10, 2023). Therefore, a recommendation for further work is to evaluate the pilot project and update Masscycle as required.

If Masscycle were to be implemented at the Swedish Transport Administration, it would be ideal to establish an administrator who can receive error reports, fix the tool if needed, and develop new features. This would result in regular updates to Masscycle, mirroring the maintenance routine of VegLCA, and facilitate the Swedish Transport Administration in achieving their anticipated project deliveries. Without an administrator who can act as support, it may be hard for Masscycle to evolve, reflecting the changes of mass management in the industry.

In PM Mass Management, consultants present mass management for their projects in different ways. One reflection from the performed case studies is that a uniform reporting of mass management would come with benefits. If all consultants follow a uniform way of reporting mass management, a strategy for follow-ups could be created. This strategy could include that Masscycle should be completed again with the results from after the construction and be compared to the planned results. An idea that was suggested during a feedback session with a project manager at the Swedish Transport Administration was the possibility to include a feature for follow-up. The employee further stated that this could be needed in order to see if the contractor had constructed as planned and to find faults in the project planning. Additionally, follow-ups could be a way to improve project planning overall. By creating follow-ups and documenting errors as well as areas of improvements, knowledge can be shared between projects, thus increasing the total knowledge on how to obtain circular and sustainable mass management within the industry. Another benefit of follow-ups is that it could improve the accuracy of the targets for the KPIs. If several projects follow this uniform way of reporting the results, the results could be used as an average when deciding the targets for the KPIs. Furthermore, these averages could be used by the Swedish Transport Administration as numbers to compare to when creating incentives for the contractors and consultants.

Because of follow-ups not being a part of the requirements document, they are not within the scope of this thesis and Masscycle was therefore not developed to include sheets for follow-ups. The inclusion of follow-ups is therefore a recommendation for further development of the tool. A suggestion if this is not developed in the future, is to open an empty version of Masscycle and fill in the tool with how the project actually turned out. Using the compilation tables and visualizations, it would be possible to draw conclusions on the differences and thus where it did not go as planned. Additionally, one could compare the outcome of the KPIs to the planned outcome of the KPIs. A specific recommendation for including follow-ups to the tool would be to add visualizations that compare planned values to result values.

As Geokalkyl is used within the Swedish Transport Administration, it would be beneficial if the two tools could be developed to be interconnected. One way this could be made possible is through using output data regarding mass quantities from Geokalkyl as input data for Masscycle. An issue with this is that the classification of

masses in Geokalkyl does not correspond to the classifications in Masscycle. In Geokalkyl, masses are classified according to geotechnical terrain classes to define the soil type (Lindgren et al., 2022). If the user wants to define the contamination level, they must use the special geotechnical terrain class for potentially contaminated soil, this eliminates previous data regarding soil type. The geotechnical terrain types do not directly correspond to the material types of AMA. Because of unspecific contamination levels and noncorresponding material types, the classification of the masses cannot be inputted from Geokalkyl to Masscycle. A possible solution would be to import the mass quantities and reclassify the masses according to the classification systems in Masscycle. It is recommended to further evaluate a possible interconnection between the two tools.

One demand in the requirements document is to provide a description of areas for storage and reloading within the work area (Trafikverket, 2022b). To investigate possible areas for storage/reloading of masses during construction, several parameters need to be known for example, the current land use, distance from area of origin, geotechnical properties of the area and the quantity of masses (Borre et al., 2022). Deciding on storage/reloading area cannot be automated in Excel and has therefore been excluded from Masscycle. In order for this demand to be fulfilled in PM Mass Management, a recommendation for further work would be to create a guide on how to choose areas for storage and relocation and an example of how it can be presented in a clear way.

The aim of Masscycle is to improve circular project planning within the road construction sector through proper documentation. This emphasis on efficient planning is essential, given that mass management not only influences construction projects but also extends its impact to the society and the environment. From a societal point of view, economy is an important factor. Construction projects are expensive, and by not utilizing excavated soil and rock masses in a circular way, resource efficiency decreases (Magnusson et al., 2015). Overall, this resource deficiency leads to a higher cost for the construction industry, which in turn has a negative effect on society. Furthermore, because of limited resources, it is not sustainable from an ethical nor ecological point of view to avoid planning for proper mass management in a construction project. Improper or non-existent mass management results in a waste of assets.

An aspect that should be taken into consideration is whether Masscycle would be useful for other types of infrastructure projects. Alternatively, how the tool could be developed to suit several types of construction works. This would largely expand the extent of the project and was therefore set as a limitation. As the requirements document applies to both road and railway construction, a tool for the planning of mass management of railway construction might not differ too much from Masscycle. In future research, the application of Masscycle on railway projects should be explored. A key difference between road realignment and track replacement projects is the length of the project. Track replacement projects often extend many miles, whereas road realignment projects usually extend several kilometres (J. Claesson, personal communication, December 15, 2023). In addition, in railway projects, when track changes are executed a large portion of the masses are returned directly to the track. Furthermore, the long distances also make it difficult for masses to be reused, as it may not be economically or sustainably beneficial to transport the masses such long distances.

6 Conclusions and Recommendations

6.1 Conclusions

From this thesis the following can be concluded:

- There is a demand for increased circular project planning in infrastructure projects to reduce the surplus of excavated material that ends up at disposal sites.
- The current information included in the reporting of data regarding environmental and technical properties of soil and rock masses is inadequate, therefore several assumptions needed to be made in order to complete Masscycle.
- Masscycle is a practical tool that fulfills the relevant demands regarding quantities and visualization in the Swedish Transport Administration's requirements document and thereby contributes to more sustainable mass management and circular project planning by creating a uniform way of reporting.
- The case studies implemented for testing Masscycle provided useful feedback to the development of Masscycle and provided the project teams of the case studies with beneficial information about their project's circularity through visualizations, KPIs and uncertainty scenarios.

6.2 Recommendations for further work

For further work concerning the future of Masscycle the functionality needs to be ensured through

- evaluating the results from a pilot project
- testing Masscycle on more projects, including other types of infrastructure projects
- evaluating the user-friendliness of Masscycle by allowing others to test the tool.

It is also important to further develop Masscycle by

- evaluating how other parts of the requirements document could be included, such as choosing areas for storage and relocation of masses and transportation aspects
- including a function for follow-up of the project
- implementing a function to be able to include uncertainties of input parameters
- developing the page matching of masses so that it is automatic or more user-friendly
- including transportation and climate impact to ensure that the tool includes wider aspects of circularity
- evaluating how Geokalkyl, Klimatkalkyl, SmartMass and the use of unmanned aerial systems and vehicles could be interconnected with Masscycle.

After ensuring the functionality and completing the development of Masscycle, implementation at the Swedish Transport Administration should be carried out to ensure a uniform way of reporting mass management.

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- [vgy5tyfmFz9Znaixtkx~mowiULG6cQZ-GRG1LGAhS-u~BECg-Hm8L4obyv1pgQ &Key-Pair-Id=APKAJLOHF5GGSLRBV4ZA](https://www.gea-ltd.co.uk/blog/detail/new-guidance-on-classification-of-waste-soil-from-construction.html)
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Appendices

Appendix A – Requirements document

This appendix contains the parts of the requirements document that are included in Masscycle. Below, a translation by the authors of the concerned parts is presented (Trafikverket, 2022b).

- A compilation in tabular form of all masses in the project with division in time and geographical location, i.e., when and where the masses emerge in the project's construction phase. All quantities must be divided and reported on the basis of technical quality (e.g., material type, frost hazard class, sensitivity) and environmental quality (e.g., content of contaminants including invasive species, value of the masses as a natural resource).

From the compilation, calculated quantities (volume in m³ and weight in tonnes with associated conversion factor) must be apparent for:

- Masses that will emerge in the project.
 - Masses that will be needed in the project.
 - Masses that can be utilized in the project.
 - Masses that are surplus or are not suitable for use in the project.

 - External masses that need to be supplied to the project.

 - Surplus masses in total, of which:
 - Surplus masses that can be used as a resource in other Swedish Transport Administration projects or externally (technically and environmentally suitable masses with a guaranteed market).
 - Surplus masses (waste) that can:
 - be prepared for material recycling or
 - be used when recycling waste for construction purposes.
 - Surplus masses (waste) that need to be taken care of at external disposal sites.
- A visualization of the compilation with division in time and geographical location.

Appendix B – Designing and programming of Masscycle

This appendix is a detailed explanation of the solutions to the problems presented in Table 4.5.

Emergenced masses

At first, emergenced masses was created as one single sheet. This seemed advantageous as the goal was to make Masscycle as easy as possible to use and one way to achieve this could be to limit the number of sheets in Excel. Upon feedback sessions with employees at the Swedish Transport Administration, it was discovered that it is fairly common to have masses within one geographical area with descending contamination levels at lower depths. Therefore, two different layers were created. In addition, it was pointed out that there may be several people within different areas filling out the tool. For example, there should be a possibility for someone working with drainage to fill in masses that emerge within that area as well as a possibility for someone else to fill in masses emergenced from road demolition on different sheets. To satisfy this demand two more sheets for emergenced masses were created. In total, four different sheets were created, called layer 1- layer 4, but can be renamed by the user to fulfil other demands such as different construction activities. Additionally, a column for comments was added if the user wanted to specify the area more in detail.

Another part of the sheets for emergenced masses that was developed with the help of reconciliations with employees at the Swedish Transport Administration was the classification of masses. At first, the alternatives for total content were MRR, <KM, KM-MKM and >MKM. After consultation with employees at the Swedish Transport Administration working in the environmental department, it was decided to exclude MRR as it is used for determining if the material needs to be reported before recycling. Furthermore, the other alternatives for total content were rephrased as “less than KM”, “between KM-MKM” and “more than MKM” as several employees pointed out that it would be clearer this way. In addition, it was suggested to include alternatives containing sulphides. Therefore, the total content was expanded to six alternatives, which were: “less than KM”, “between KM-MKM”, “more than MKM”, “less than KM, sulphides”, “between KM-MKM, sulphides”, and “more than MKM, sulphides”.

Through the brainstorming session, another parameter to classifying masses was identified, leachability. Leachability was in the reconciliation stage determined to be misleading, as leachability is not often used to classify excavated masses that will be used in construction works. It is always used to classify waste masses that are to be disposed of at disposal sites. This classification was therefore removed from emergenced masses and added to the sheet for surplus masses and called waste classification.

During a reconciliation session it was recommended to add a feature that would let the user specify the type of emergenced mass, for example asphalt or concrete. Because the limitation was set to only include rock and soil masses, this feature was not included.

Needed masses

In the sheet, needed masses, when the construction code is entered, the material type and description are added automatically. For some construction codes, there exist comments that specify conditions for when a certain material type is not suitable.

Therefore, as a user it is important to read the comments in AMA Anläggning 23, so that the wrong material type is not used for the specific construction task.

Furthermore, the areas with a need are not the same as the areas of origin. This is to create a bigger freedom for the user, as area with a need and origin are not always the same. If the user would like to have the same division of area in needed masses as in emerged masses, it is possible to copy and paste between the sheets.

Matching of masses

One goal for Masscycle was to make the tool as easy as possible to use, but the sheet matching of masses may not be entirely user-friendly. In order to match needed masses with emerged masses, broad knowledge about the project and mass management is needed. To make it easier for the user, an assisting guide regarding what to consider during the matching is included in the instructions for Masscycle, see Appendix C.

In the brainstorming stage, one idea that came up was to create an automatic matching between the emerged masses and needed masses. During the creation of Masscycle, it was discovered that this would not be possible. There were several reasons for this. Firstly, because of the exceptions for certain material types in the construction codes. The exceptions are found in the comments and cannot be automatically programmed as they require project specific information. Secondly, in order for the matching to be done automatically, a prioritization of the most desired masses would need to be done. This prioritization would require specifying which different combinations (invasive species, material type, suitable with or without treatment, vicinity and contamination level) are most to least suitable. Thirdly, this prioritization may be different for different projects. Deciding which need is best matched with emerged masses, was therefore designed as a manual part of Masscycle.

Several attempts were made to increase the ease of use for the matching. During a reconciliation session with employees, it came up that it would be beneficial to be able to filter amongst the material types and see one at a time thus eliminating the need for excessive scrolling. This would also minimize errors regarding missed opportunities for matching, as a single row of data easily can be missed in a large table. None of the attempts were successful and the conclusion was drawn that to fix this problem, another software may be required.

Utilized masses

One difficulty that was discovered when creating the sheet for utilized masses was how the weight of the masses should be calculated. In needed masses, only the volume of masses is specified, this is because the material type is unknown and thus also the conversion factor to tonnes. If the area with a need is matched with several areas of origin, there will be several material types in the column for utilized material type. Because of this, Masscycle does not know which conversion factor to use when calculating the weight. To overcome this problem, Masscycle is programmed to print the text "Fill in weight manually" in the cell *Masses (tonnes)* for the rows with several areas of origin.

Compilation sheets

In the brainstorming session, the idea came up to create a compilation sheet with only the most essential information. During the design phase, this idea was changed. Instead of only presenting a fairly short overview of the project, it was decided to create two compilation sheets, the first one more general, and the second one more in depth. The reason for this idea being changed, was that many ideas for different visualizations came up, and since one of the goals for Masscycle was to keep it as user-friendly as possible, two sheets seemed like the best solution.

Concerns were raised regarding the potential negative impact of an excessive number of visualizations. Determining the optimal threshold for the quantity of visualizations is challenging. An excess of visualizations could make it difficult for users to locate those most relevant to their needs. On the other hand, an insufficient number may fail to convey the full scope of the project, potentially leading to oversight of time-critical phases. The goal was to achieve a balance in the number of visualizations, ensuring they are neither overwhelming for users nor inadequate to represent various project scenarios effectively.

Creating various visualizations posed a challenge as some of them could not be fully automated. During the visualization creation process, all cells in the relevant table were included in the data set for the corresponding visualizations. However, if a user would choose not to input a geographical location for all available cells (which is optional), it would result in empty spaces in some diagrams.

The compilation sheets feature three types of diagrams: pie charts, sunburst diagrams, and bar charts. Both pie charts and sunburst diagrams function automatically regardless of the data input. In contrast, bar charts, relying on geographical locations for the x-axis, include an empty data range after the last entered geographical location when data is incomplete. Numerous attempts were made to address this issue, employing filters and macros, but these functions proved ineffective in resolving the problem. As a workaround, a guide on modifying the input data for the diagrams was incorporated into the instructions for Masscycle. Given that basic Excel skills are a prerequisite for using Masscycle, adjusting input data should not pose a significant challenge for users.

Appendix C – Instructions for Masscycle

Overall

White cells should be filled in manually, grey cells are filled in automatically.

Figure C.1 is an example of what cells containing a comment look like. The red triangle indicates that there is a comment. To view the comment, place the mouse cursor over the cell.

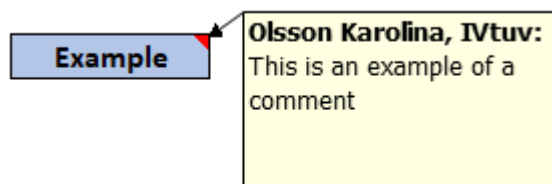


Figure C.1 An example of what a comment looks like in Excel.

Project specific data

In Figure C.2 the sheet for project specific data in Masscycle is presented.

Geographical division: The stretch can be divided into sections or areas. Choose how you want the stretch to be divided by filling in the cells under the appropriate heading. For section division, fill in section start, section end, and section length, and the different sections will be generated in the upcoming sheets. If a specific area/phase is chosen instead, list them in order.

Conversion factor: Fill in the conversion factor from cubic meters (m³) to tonnes for all material types. This factor will be used to convert volumes from cubic meters to tonnes throughout the tool.

- Himalayan Balsam
- Common Blue-Sow-Thistle
- Persian Hogweed
- Giant Hogweed
- Japanese Knotweed
- Beach Rose

For material type, specify the material type (according to AMA table CE/1 and CE/2) of the emerged masses. The following options can be chosen:

- 1.
- 2.
- 3A
- 3B
- 4A
- 4B
- 5A
- 5B
- 6A
- 6B
- 11.
- 12a
- 12b
- 13.
- 14.
- 15.

For contamination level, specify the contamination level for the emerged masses, also include if they contain sulphides. The following options can be chosen:

- Under KM
- Between KM-MKM
- Over MKM
- Under KM and sulphides
- Between KM-MKM and sulphides
- Over MKM and sulphides

For land area, answer the question regarding which land area the emerged masses belong to. One should not classify the area of origin. The following options are available:

- L1
- L2
- S1
- S2

The classification of masses will then help the user determine whether the masses in that area can be considered suitable for the project. This implies that there is a belief that there is a utility for the masses; precise knowledge is not necessary. Fill in by choosing one of the options: "Yes," "With treatment," and "No." The masses marked with "Yes" or "With treatment" will be further examined in a later step to determine if they will be used in the project.

Once you have filled in the entire layer, you can choose to click on the "Add layer" button to move to a new sheet to fill in another layer. Alternatively, press "Next step" to proceed to the compilation

Needed masses

In this sheet, the extent of the project's need for masses is specified, which is presented in Figure C.5.

Area with a need: Indicates where the need for the masses exists.

Construction code, description and material type: Specify what the masses will be used for using the construction code from AMA Anläggning 23. The description of the construction code and the applicable material types will be filled in automatically. NOTE! There may be exceptions when certain material types cannot be used for a specific construction code, so always double-check in AMA Anläggning 23.

Comment: Here you can choose to specify if the masses are not allowed to be contaminated beyond a certain limit. This can be conveniently done by classifying the areas of need with land area. This column can also be used to input comments, such as a note indicating that the area with a need is within a water protection zone.

Matching of masses

This sheet is designed for the user to match the need for masses with the emerged masses deemed suitable for the project. This matching process has to be done manually. To match the masses, in the yellow area (needed masses), assess the magnitude of the need, allowed contamination levels, and the required material type. In the blue area, also consider the material type and classification of the masses. Another aspect to consider is whether you have indicated that masses can be used with or without treatment, since it is more convenient if no treatment is required. If you believe that a row in the needed masses should be matched with a row of emerged masses, input the same match code (preferably a number) in the matching code cell for that row. Once you have filled in the match codes in the yellow and blue areas, the "Updated need" column will be updated to reflect the adjusted need after the matching. If there is a need for masses but they cannot be matched with the emerged masses, write a hyphen in the matching code for the needed masses. The sheet for matching of masses in Masscycle is presented in Figure C.6.

It is possible to match multiple areas of emergence to one area of need, but not vice versa. If you want to work around this, combine the areas of need into one large area with more masses in the "Needed masses" sheet. Alternatively name match codes related to each other with the same number and a letter afterwards, e.g., 1A, 1B.

Utilized masses

For some masses, the weight may not be automatically filled in. In such cases, it will say " Fill in weight manually" in the mass (tonnes) column for that row. Enter the weight for those masses in the cell that says "Fill in weight manually". The sheet for utilized masses compiles all masses from the previous tab that were matched and reports the origin area, area of need, quantity of utilized masses, mass balance (surplus/deficit), and the characteristics of the masses. The sheet for utilized masses in Masscycle is shown in Figure C.7.

Externally needed masses

The sheet for externally needed masses is presented in Figure C.8 and is fully automated. It reports the quantity of external masses needed, based on the need that was not matched with generated masses.

Surplus masses

In this sheet, presented in Figure C.9, all surplus masses from the project are displayed, including those that were not deemed suitable for the project in the emerged masses, and those that were left over after the matching of masses. This sheet details where surplus masses arise, the quantity in cubic meters and tonnes, and their characteristics. For some masses, the weight may not be automatically filled in. In such cases, it will say " Fill in weight manually" in the mass (tonnes) column for that row. Enter the weight for those masses in the cell that says "Fill in weight manually".

The next step is to assess whether the masses are a resource, potential resource, or not a resource. This is done in the *Resource?* column. The meanings are as follows:

Resource: Surplus masses that can be used as a resource in other Swedish Transport Administration projects or externally (technically and environmentally suitable masses with guaranteed market).

Potential Type 1: Surplus masses (waste) that can be prepared for material recycling.

Potential Type 2: Surplus masses (waste) that can be used in waste recycling for construction purposes.

Not a Resource: Surplus masses (waste) that need to be handled at external disposal sites.

For masses where the "Not a Resource" option has been chosen, you need to specify waste classification. This indicates the type of disposal sites the masses need to be sent to. Choose from the options "inert," "non-hazardous" or "hazardous".

For masses where the "Resource" option has been chosen, you need to specify resource classification. This indicates whether the masses need to be reported to the regulating authority before use. Choose from the options "less than MRR" or "more than MRR".

Compilation

This sheet presents a summary of the masses in the project in tabular form with accompanying visualizations, as seen in Figure C.10.

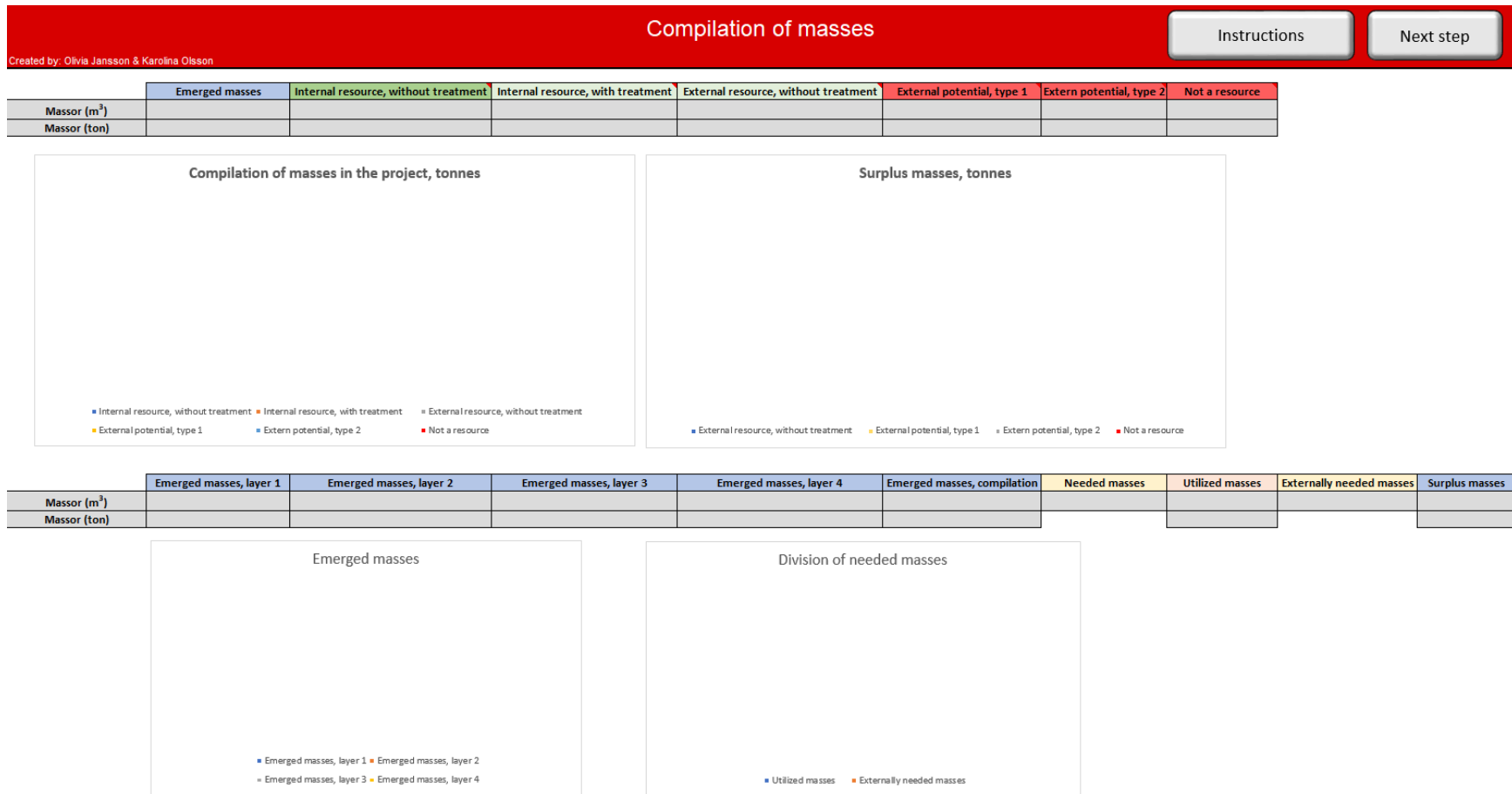


Figure C.10 The sheet for the overview compilation in Masscycle.

Detailed compilation

This sheet presents several visualizations, some more general and others more specific. For visualizations categorized by geographic area, you may need to reduce the input range to remove empty cells.

To do this:

- Right-click on the chart
- Click on "Select Data..."
- Select a series in the box on the left, click on "Edit"
- Modify the input range so that it does not include empty cells
- If there are multiple series in the chart, edit them as well.

The visualizations in the tool can be used to identify time-critical phases in the project.

Key performance indicators

KPIs and targets for KPIs are a way to measure the project's circularity. Most KPIs can be calculated with previous input in the tool, but some require additional input. The specified targets for KPIs are recommended based on literature but can be adjusted from project to project if desired. The sheet for KPIs is presented in Figure C.11.

Key performance indicators

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Key performance indicators	Target for KPI	Current value
Relation between externally needed masses in m ³ and total needed masses in m ³	0%	
Relation between recycled masses (internal and external) in tonnes and total emerged masses in tonnes	100%	
Relation between internal resources in tonnes and masses identified as suitable for the project in tonnes	100%	
Relation between internal resources in m ³ and total needed masses in m ³	100%	
Relation between masses that have been met by recycled masses (from this project or another) in m ³ and total needed masses in m ³	100%	
Relation between total internal resources in tonnes and internal resources that needed treatment		
Relation between virgin needed masses from quarry in m ³ and total needed masses in m ³	0%	
Relation between approved permits for disposal sites and all applied permits for disposal sites	100%	
Relation between masses in tonnes that are sent to disposal sites and the capacity of the disposal sites	↓	
Relation between total project cost in SEK and the mass management cost in SEK		
Mass management cost for project in SEK per meter of project		
Relation between sampling cost in SEK and internal resources in tonnes		
Relation between sampling cost in SEK and recycled masses (internally and externally) in tonnes		
Relation between sampling cost in SEK and total emerged masses in tonnes		
Sampling cost in SEK per tonnes of waste produced by the project		

To get results from as many key figures as possible, fill in the squares below.

Divide the externally needed masses, by specifying the share of the categories below:

Externally needed masses in terms of virgin masses from quarry	
Externally needed masses in terms of recycled masses from other projects	

Number of applied permits at disposal sites	
Number of approved permits at disposal sites	
Capacity of disposal sites in tonnes	

Length of project in meters	
Total project cost in SEK	
Mass management cost for project in SEK	
Sampling cost for project in SEK	

Figure C.11 The sheet for key performance indicators in Masscycle.

Appendix D – Results from case studies

Project Road 41

Figure D.1 presents a division of the emerged masses according to contamination level and material types.

Emerged masses		
Contamination level	m ³	tonnes
Below KM	14 688	20 634
Between KM - MKM	-	-
Above MKM	1 116	1 673
Below KM, sulphide	-	-
Between KM - MKM, sulphide	-	-
Above MKM, sulphide	-	-
Material type	m ³	tonnes
1	-	-
2	-	-
3A	-	-
3B	1 000	1 700
4A	-	-
4B	1 700	2 890
5A	2 174	3 696
5B	1 802	2 703
6A	1 825	2 555
6B	7 303	8 764
11	-	-
12a	-	-
12b	-	-
13	-	-
14	-	-
15	-	-

Figure D.1 Compilation of masses in m³ and tonnes according to contamination level and material types for project Road 41.

Figure D.2 shows that 7% of the emerged masses in project Road 41 are above MKM and 93% are below KM.

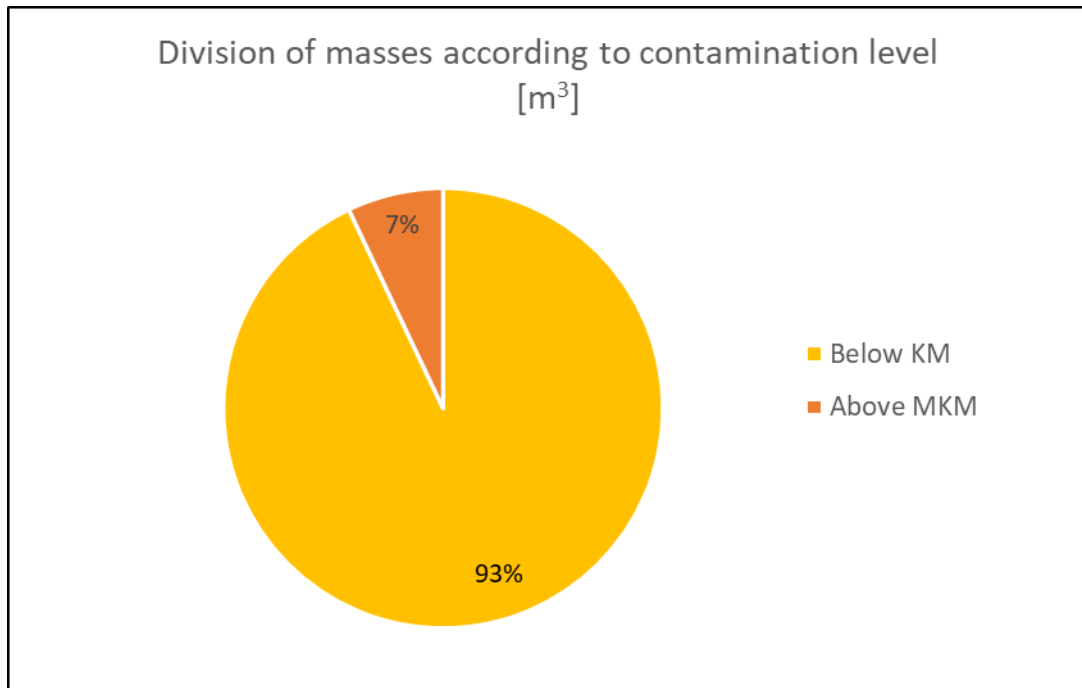


Figure D.2 Division of masses in m^3 for project Road 41 according to contamination level.

Figure D.3 presents a division of masses in project Road 41 according to material type.

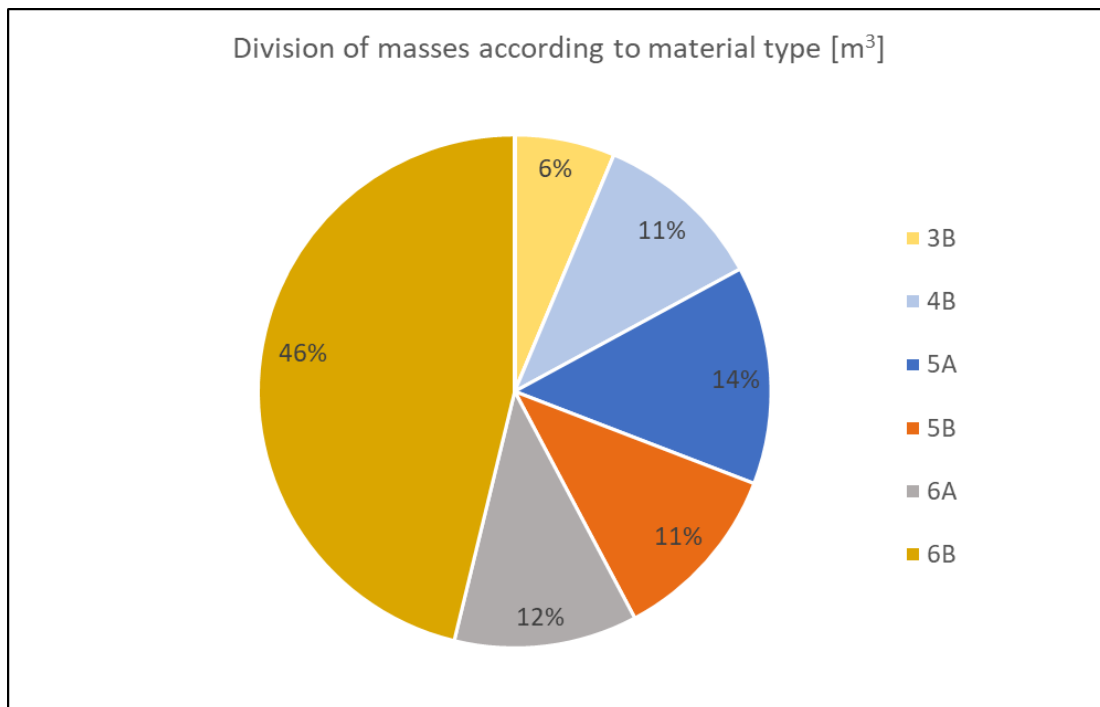


Figure D.3 Division of masses in m^3 for project Road 41 according to material type.

Project B

Figure D.4 presents a division of the emerged masses according to contamination level and material types.

Emerged masses		
Contamination level	m ³	tonnes
Below KM	810 872	1 441 333
Between KM - MKM	3 380	4 732
Above MKM	-	-
Below KM, sulphide	-	-
Between KM - MKM, sulphide	-	-
Above MKM, sulphide	-	-
Material type	m ³	tonnes
1	211 033	422 066
2	172 949	328 603
3A	-	-
3B	177 340	301 479
4A	-	-
4B	68 152	115 859
5A	64 569	109 767
5B	-	-
6A	120 208	168 291
6B	-	-
11	-	-
12a	-	-
12b	-	-
13	-	-
14	-	-
15	-	-

Figure D.4 Compilation of masses in m³ and tonnes for project B divided according to contamination level and material type.

Figures D.5, D.6 and D.7 present a division of the emerged masses according to material type for the original case, scenario 1 and scenario 2 respectively.

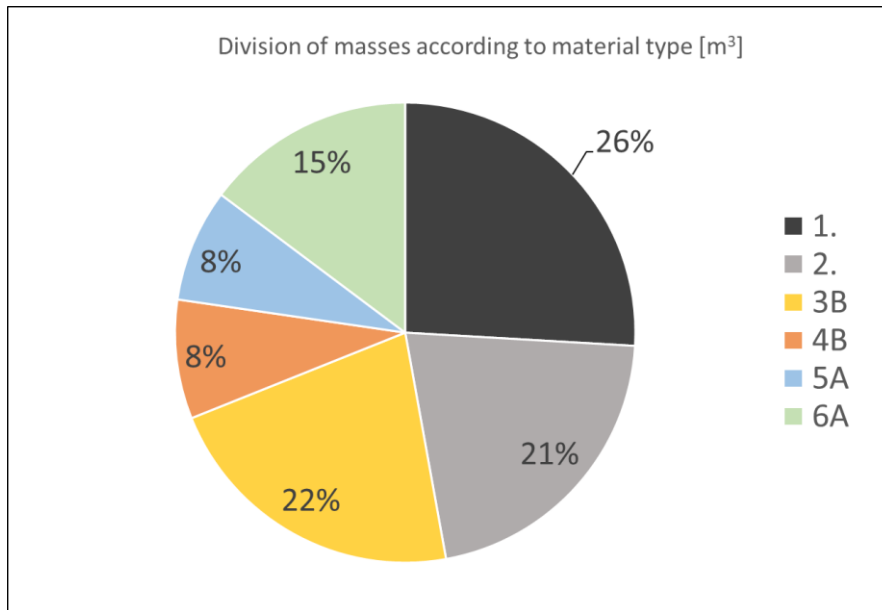


Figure D.5 Division of masses in m³ for project B according to material type.

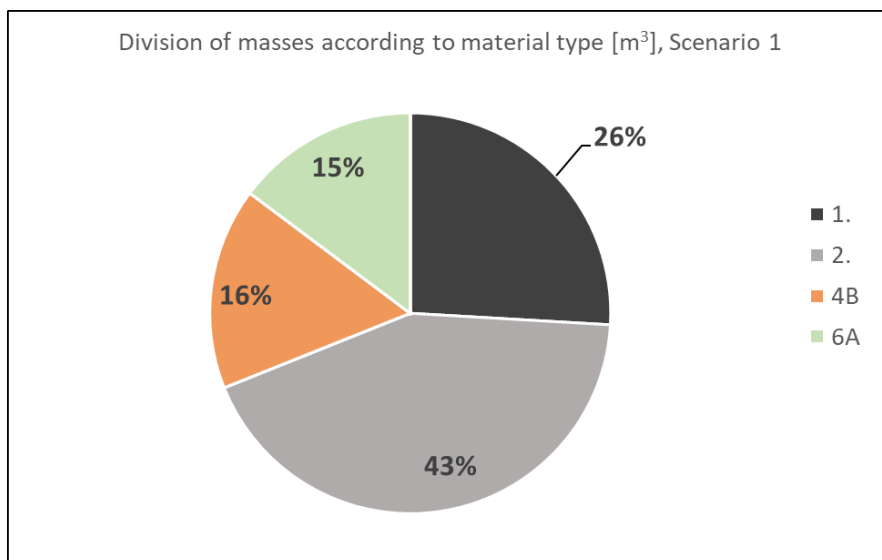


Figure D.6 Division of masses in m³ according to material type for project B, scenario 1.

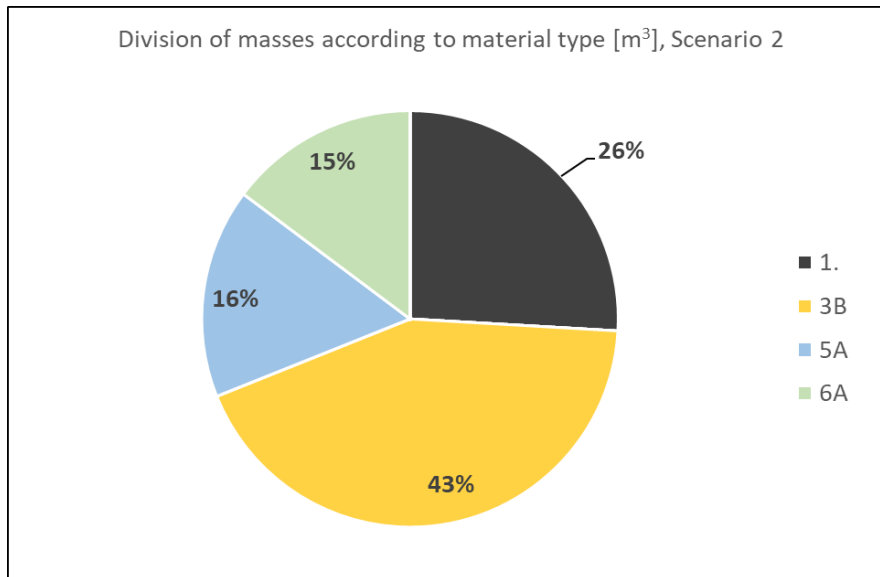


Figure D.7 Division of masses in m³ according to material type for project B, scenario 2.

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