Towards the understanding of system level impacts of changes on the sustainability of the urban freight transport system

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Half-time seminar summary

October 2022

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Abstract

In the urban logistics system, there are various sustainability challenges, as transport-related externalities affect the liveability of the urban environment and the health of citizens. The main goal of this research is to understand the impacts of changes on the sustainability of the urban freight transport system, through surveys, interviews and system dynamics modelling. During the first two years, the research included the development of a list of indicators for sustainability performance assessment and evaluation of the urban logistic practices of electrification, consolidation, cargo bikes and automation. A qualitative system dynamics model of the implementation of city hubs as a practice was developed: this model can help decision-makers in the private and public sectors to make decisions that facilitate a more sustainable urban freight transport system. As COVID-19 affects the urban logistics system, this research includes the study of the effects of COVID-19 on e-commerce and behavioural changes in shopping activities.

1 Introduction

The transportation of goods within the city boundaries, i.e., the urban freight transport system, is responsible for a variety of externalities (for example, air pollution, noise, accidents, vibration, land use and visual intrusion) (McKinnon et al., 2015). The growth of the freight flows expected in the future (Bosona, 2020) will further increase the impacts of these externalities. Many cities in the world are setting targets for decreasing these impacts. For example, one of Stockholm's vision for 2040 is to have fossil-free transport solutions (Stockholm Stad, 2020). Furthermore, in terms of urban logistics, Stockholm's vision is to decrease congestion through increased efficiency and coordination (Stockholm Stad, 2020). As more and more people will live in cities in the future, and as the growth of e-commerce increases the need for goods transportation (Castillo et al., 2018; Cleophas and Ehmke, 2014; Sheth et al., 2019), it is important to plan for a sustainable urban freight transport system.

To reduce the impacts of the urban freight transport system and increase sustainability in cities, new solutions for city logistics have been designed and several projects have been undertaken in the past years (Jamshidi et al., 2019). In this work, *sustainable urban logistics practices* are defined as all activities that aim to increase the sustainability of the urban freight transport system. Examples are electrification and automation, business models for collaboration and consolidation, and co-modality (Elbert et al., 2020). In the literature, these sustainable urban logistics practices are evaluated in terms of sustainability. However, despite the literature is extensive, the impact of these practices in terms of sustainability is often measured only through few indicators, mostly connected with the environmental dimension of sustainability. There is a lack of a holistic view or system perspective of the urban freight transport system as a whole, and a lack of understanding of the impacts of such urban logistics practices on the overall system.

The successful implementation of these practices is influenced by the diversity of the actors and stakeholders in the urban freight transport system. In this research, stakeholders are referred to as all that have an interest in a system, while actors as all that have a direct influence in a system, as defined in Ballantyne et al. (2013). Ballantyne et al. (2013) defines shippers, LSPs, authorities and customers as the actors, and citizens, vehicle manufacturers, landowners, public transport operators, and trade and commercial organisations as stakeholders. Public actor and the policy setting is of utmost importance in the urban freight transport system, as many urban logistics practices are implemented by the governing bodies in terms of policies or measures that force the private sector to change their behaviour (Anderson et al., 2005). The complexity of the urban freight transport system is illustrated in part by the diversity of the stakeholders and actors involved and by their varying scopes and purposes. Despite the large number of initiatives from different actors and stakeholders, the sustainability of the system is improving very slowly (if at all).

The need to take a holistic approach, combined with the importance of the policy-setting, makes a system thinking lens useful (Sterman, 2001). Therefore, in this work, a *system thinking* lens is used to understand the impacts of different *changes* in the urban freight transport system from a sustainability perspective. *Changes*, in this work, refers to the introduction of new urban logistics practices but also unexpected changes in demand or supply, and unexpected events such as COVID-19. These changes can be implemented by governing bodies, private sector driven or unexpected/unplanned. The application of *system thinking* enables the understanding of the relations and functions of the elements within the overall system (Sterman, 2001). System thinking is used as a fundamental paradigm throughout this research. In terms of methods, literature reviews are carried out throughout the work, together with qualitative methods for data collection such as surveys, interviews and workshops. Multivariate statistical analysis is also used to analyse the output of online surveys. The modelling included in this research is so far only done at a qualitative level,

using system dynamics as a method. The system dynamics method allows the dynamics of the system to be captured, and internal rebound effects and causal reactions to be considered (Sterman, 2001). Moreover, in a system with many uncertainties, it is important to be able to include these uncertainties and simulate different possible future scenarios.

In the next subsection, the research goals and questions are described. Then, the overview of the included publications is included. Each paper is described in terms of content, results and takeaways, and it is connected to the research goals and questions. The future work section then concludes the report.

2 Research goal and questions

The main goal of this research is to understand the impacts of changes on the urban freight transport system from the perspective of sustainability, through survey, interview methodologies and system dynamics modelling. The main research question is therefore ***How do different* changes *impact the urban freight transport system in terms of sustainability?***. To narrow down this broad main research question, four research questions are reported below, with related subquestions.

RQ1: *How can the sustainability of the urban freight transport system be measured?*

(a) What indicators are suitable to be used for assessing sustainability in the urban freight transport system?

(b) How can perspectives of different actors and stakeholders be considered when assessing sustainability?

(c) How can an urban freight transport system be designed so that it contributes towards the Sustainable Development Goals (SDGs)?

RQ2: *What urban logistics practices would lead to a sustainable urban freight transport system?*

(a) How can the sustainability of urban logistics practices be assessed?

(b) What aspects are needed to evaluate their sustainability?

(c) What are the most common urban logistics practices and how do they perform in terms of sustainability?

RQ3: *How can the impacts of the changes in the urban freight transport system be modelled?*

(a) What parameters are the most important when modelling an urban delivery system to capture these changes?

(b) What are the main dynamics that should be considered in an urban delivery system?

RQ4: *How did COVID-19 affect the urban freight transport system?*

(a) What are the effects of COVID-19 on the urban freight transport system due to the change in behaviour of people and companies?

(b) What should be considered by policy-makers when designing policies to mitigate these effects?

3 Included publications

The following papers and reports are the results of the first two years of the PhD project. In the next sections the papers are summarized and connected to the research questions.

Paper I Andruetto, C., Bin, E., Susilo, Y., & Pernestål, A. (2022). Transition from physical to online shopping alternatives due to the COVID-19 pandemic. Characterizing Health Pandemic Impacts on Transportation Systems and the Demand for Mobility, Transportation Research Part A. Status: Under review. Preprint url `https://arxiv.org/ftp/arxiv/papers/2104/2104.04061.pdf`. **Authors' contributions**. Claudia Andruetto: ideation of the study, design of the survey, analysis of the data, interpretation of the results, review of the existing literature, reviewing and editing. Elisa Bin: ideation of the study, design of the survey, analysis of the data, interpretation of the results, review of the existing literature, reviewing and editing. Yusak Susilo: ideation of the study, analysis of the data, interpretation of the results, review of the existing literature, reviewing and editing. Anna Pernestål: ideation of the study, review of the existing literature, reviewing and editing.

Paper II Andruetto, C., von Wieding, S., Mårtensson, J., & Pernestål, A. (2022). Indicators for Sustainability Assessment in City Logistics: Perspectives of Society and Logistic Service Providers. Transportation Research Board (TRB). Annual Meeting, Washington, USA. Status: Accepted. **Authors' contributions**. Claudia Andruetto: study conception and design, data collection, analysis and interpretation of results, manuscript writing and reviewing. Jonas Mårtensson: study conception and design, manuscript reviewing. Sönke von Wieding: study conception and design, manuscript reviewing. Anna Pernestål: study conception and design, manuscript reviewing.

Paper III Andruetto, C., Mårtensson, J., & Pernestål, A. (2022). Categorization of urban logistics concepts according to their sustainability performance. Transportation Research Procedia. Transport Research Arena (TRA) Conference, Lisbon, Portugal. Status: Accepted. **Authors' contributions**. Claudia Andruetto: study conception and design, literature review and data collection, analysis and interpretation of results, manuscript writing and reviewing. Jonas Mårtensson: study conception and design, manuscript reviewing. Anna Pernestål: study conception and design, manuscript reviewing.

Paper IV Andruetto, C., Stenemo, E., & Pernestål, A. (2022). Exploring city hubs by using a qualitative system dynamics approach. Conference proceedings. International System Dynamics Conference, Frankfurt, Germany. Status: Accepted and Presented. **Authors' contributions**. Claudia Andruetto: conceptualization, investigation, methodology, visualization, writing of original draft, reviewing and editing. Erik Stenemo: conceptualization, investigation, methodology, reviewing and editing. Anna Pernestål: conceptualization, methodology, supervision, reviewing and editing.

Report I Andruetto, C. (2022). Exploring electrification, consolidation, cargo bikes and automation using a sustainability performance assessment framework. `http://urn.kb.se/resolve?urn=urn:nbn:se:kth:diva-311386`

3.1 Other publications

Three more papers have been written during the time period, which are regarded as additional work and not connected to the research questions. These are listed below.

Paper V Bin, E., Andruetto, C., Susilo, Y., & Pernestål, A. (2021). The trade-off behaviours between virtual and physical activities during the first wave of the COVID-19 pandemic period. Eur. Transp. Res. Rev. 13, 14. `https://doi.org/10.1186/s12544-021-00473-7`. **Authors' contributions**. Elisa Bin: ideation of the study, design of the survey, analysis of the data, interpretation of the results, reviewing and editing. Claudia Andruetto: ideation of the study, design of the survey, analysis of the data, interpretation of the results, reviewing and editing. Yusak Susilo: ideation of the study, analysis of the data, interpretation of the results, reviewing and editing. Anna Pernestål: ideation of the study, review of the existing literature, reviewing and editing.

Paper VI Zhao, X., Andruetto, C., Vaddadi, B., & Pernestål, A. (2021). Potential values of maas impacts in future scenarios. Journal of Urban Mobility, 1, 100005. `https://doi.org/10.1016/j.urbmob.2021.100005`. **Authors' contributions**. Xiaoyun Zhao: Writing – original draft, Conceptualization, Methodology, Writing – review & editing, Investigation, Funding acquisition. Claudia Andruetto: Methodology, Data curation, Writing – review & editing. Bhavana Vaddadi: Methodology, Visualization, Writing – review & editing, Investigation. Anna Pernestål: Writing – review & editing, Investigation, Funding acquisition.

Paper VII Chiche, A., Andruetto, C., Lagergren, C., Lindbergh, G., Stenius, I., & Peretti, L. (2021). Feasibility and impact of a Swedish fuel cell-powered rescue boat. Ocean Engineering, 234, 109259. `https://doi.org/10.1016/j.oceaneng.2021.109259`. **Authors' contributions**. Ariel Chiche: Conceptualization, Methodology, Software, Validation, Investigation, Formal analysis, Writing - original draft, Writing - review & Editing, Visualization. Claudia Andruetto: Conceptualization, Methodology, Software, Validation, Investigation, Formal analysis, Writing - original draft, Writing - review & editing, Visualization. Carina Lagergren: Resources, Writing - review & editing, Supervision, Project administration, Funding acquisition. Göran Lindbergh: Resources, Writing - review & editing, Supervision, Project administration, Funding acquisition. Ivan Stenius: Resources, Writing - review & editing. Luca Peretti: Resources, Writing - review & editing, Supervision, Project administration, Funding acquisition.

4 Overview of included publications

4.1 Paper I: Transition from physical to online shopping alternatives due to the COVID-19 pandemic

Main content. In this paper, the impact of the first wave of COVID-19 on shopping activities is investigated using the responses of an online questionnaire. The study identifies who changed the shopping behaviour the most and how, what are the different shopping strategies and who adopted them. The impact of COVID-19 on e-commerce is analysed from an individual behaviour perspective, and policies that can be implemented to increase the resilience of the system are identified. The responses of the questionnaire are collected from two countries, Italy and Sweden. These two countries are interesting to compare because of the large difference in terms of policies related to COVID-19; i.e., in Italy, these policies have been much more restrictive than in Sweden. A comparative statistical analysis is used as main methodology to analyse the questionnaire results.

Main results and takeaways:

- In Italy, there has been a larger increase in online shopping and a larger reduction in physical trips during the pandemic compared to Sweden. This is in line with the difference in policies in the two countries and the fact that online shopping was less popular in Italy than in Sweden prior to the pandemic.
- In terms of items, in Italy, work-related items were bought more than in Sweden; prior to the pandemic, in Italy workers and students were not prepared for remote working.
- The household structure influenced the behaviour in different ways. For example, having elderly members in the household impacted the precautions that the other members took. These households can be categorised as a risk group who may end up being socially excluded. On the other hand, having children in the household is correlated with continuing to visit non-grocery physical shops.
- The results confirm the need for different policy strategies to help different groups of citizens to comply with pandemic-related measures, whilst still being able to fulfil their individual shopping needs.

Connection to the research questions and goals. As the goal of the research is to understand the impacts of changes on the urban freight transport system, in this first paper a survey is used to analyze the impacts of COVID-19. The pandemic has brought many challenges to the supply chain, and it has been seen as an opportunity to analyse the shift in shopping activities. This paper relates to the overall goal of this research, to understand the impacts of changes in the urban freight transport system, and specifically to RQ4. The COVID-19 pandemic is certainly a good example of a sudden and unexpected change that disrupted the transport systems greatly. In the paper the effects of COVID-19 on the urban freight transport system are discussed (answering to RQ4a, even if just partially), together with how different policy strategies are needed to help different groups of people (targeting RQ4b).

4.2 Paper II: Indicators for Sustainability Assessment in City Logistics: Perspectives of Society and Logistic Service Providers

Main content. In the previous literature, there is a focus on green logistics, defined by McKinnon et al. (2015) as the study of the environmental effects (mainly greenhouse gas emissions) of the activities involved in transporting, storing, and handling physical products as they move through the supply chain. Social issues are also essential to sustainable development, but they have not been studied extensively in the previous literature. In this paper, the focus is on sustainability with a more holistic perspective than just the environment. The starting points of this paper are the Sustainable Development Goals (SDGs), that provide a holistic view of sustainability, and existing indicators in the city logistics literature, to ensure relevance to the context. From these starting points, a set of indicators is identified, from the perspectives of both the citizens as stakeholders and the Logistics Service Providers (LSPs) as actors. This set of indicators can be used to evaluate urban logistics practices, with the aim of increasing the knowledge that actors in the urban freight transport system have regarding these practices. This knowledge can help decision-makers in the private and public sectors to make decisions that facilitate a more sustainable urban freight transport system.

Main results and takeaways:

- The main result of the paper is the set of indicators that can be seen in Figure 1.
- The strengths of the set of indicators are: i) it is selected starting from the SDGs, giving a holistic view of sustainability; ii) the literature is used to ensure the relevance to the city logistics context; iii) the indicators are defined both at the societal level (i.e., how the urban freight transport system affects the citizens as stakeholders in the system) and at the LSP level (i.e., how the LSPs' actions affect the societal indicators and how the LSPs' costs are affected).
- In the indicator selection process, a balance is needed between aggregation and specificity. A large number of indicators would make the assessment overly complex; the contrary would not allow for a holistic view of sustainability.

Connection to the research questions and goals. Paper II targets RQ1, related to sustainability measuring, and partly RQ2. The paper includes a proposal for a definition of sustainable logistics practices, which goes beyond just considering environmental issues but including also societal issues and economical perspectives. The selection of the indicators is carried out, to answer RQ1a, and it is done using the SDGs as starting points (RQ1c). Moreover, the indicators are defined both from the perspective of the citizens as stakeholders and of LSPs as actors (answering RQ1b). The proposal is that these indicators can be used to evaluate urban logistics practices (RQ2a and RQ2b). Paper II targets partially also RQ3a, by understanding what parameters are important to use and monitor when modelling a urban freight transport system (i.e., the indicators). The set of indicators is used as methodology in Paper III and in the Report I, which provide an example of how the set of indicators can be used successfully to evaluate sustainability performance.

4.3 Paper III: Categorization of urban logistics concepts according to their sustainability performance

Main content. In this paper, the set of indicators identified in Paper II is used as a methodology to analyze the urban logistics practices of electrification, consolidation, cargo bikes and automation. A literature review is performed to select papers that contain results (from simulations or case studies regarding these practices) that can be used as input to evaluate sustainability using the set of indicators. The results of the entire literature review are available in Report I. To make informed decisions, actors and stakeholders in the system need knowledge about the sustainability of urban logistics practices. The findings presented in this paper are a first step towards this required knowledge.

Main results and takeaways:

- The Sustainability Performance Assessment (SPA) matrix presented in Figure 2 is the main result of this paper, which can be used as a tool for comparing the practices and understanding how they can be combined to achieve integrated benefits. Report I contains more detailed information and the full list of references that are used as input to create the SPA matrix.
- From the SPA matrix, it can be seen that all four concepts contribute to a reduction of air pollution in the urban environment.

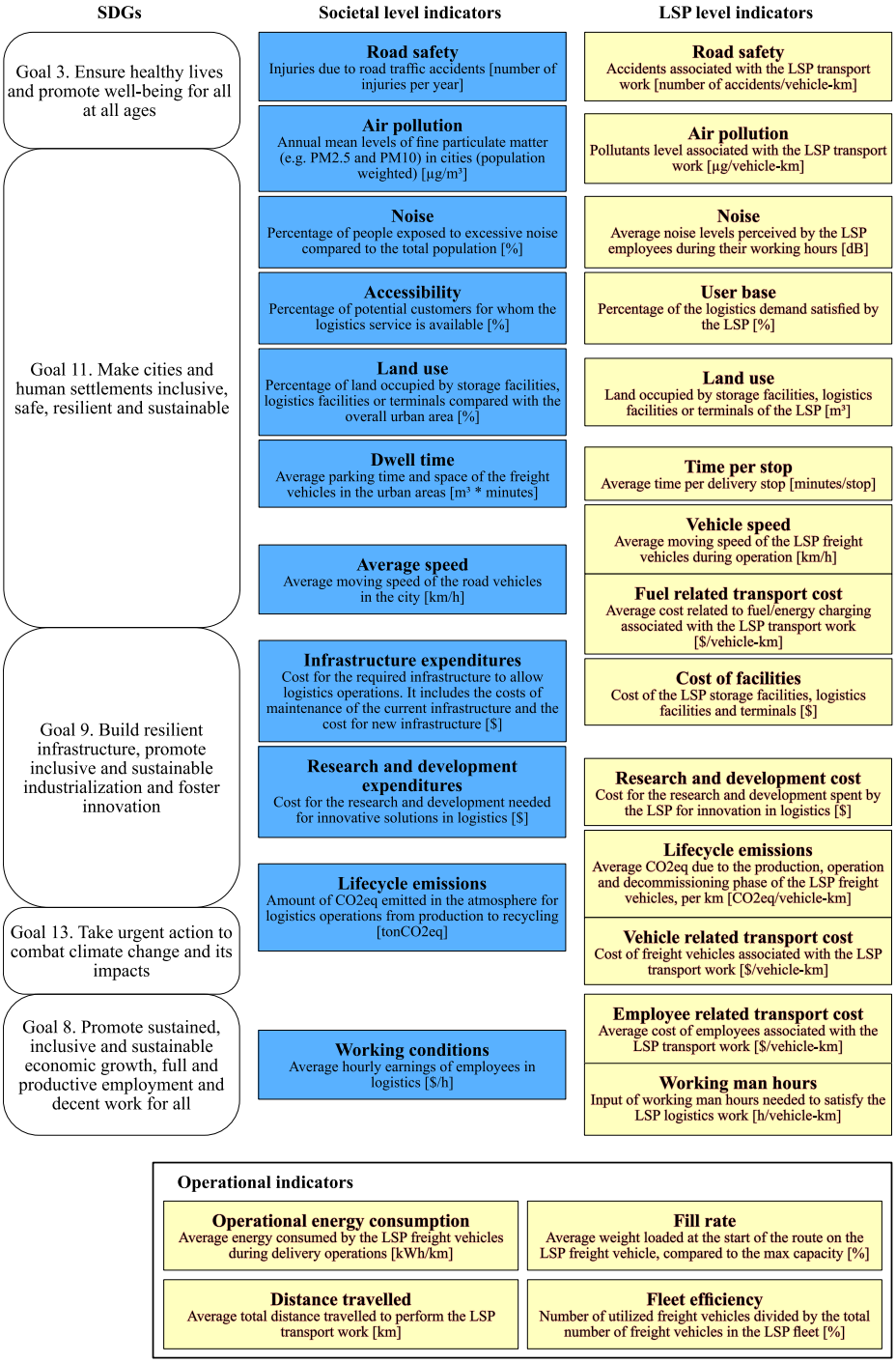

Figure 1: Visual representation of the set of indicators. The SDGs are listed on the left, the societal level indicators are listed in the center in blue and the LSP level indicators are listed on the right in yellow.

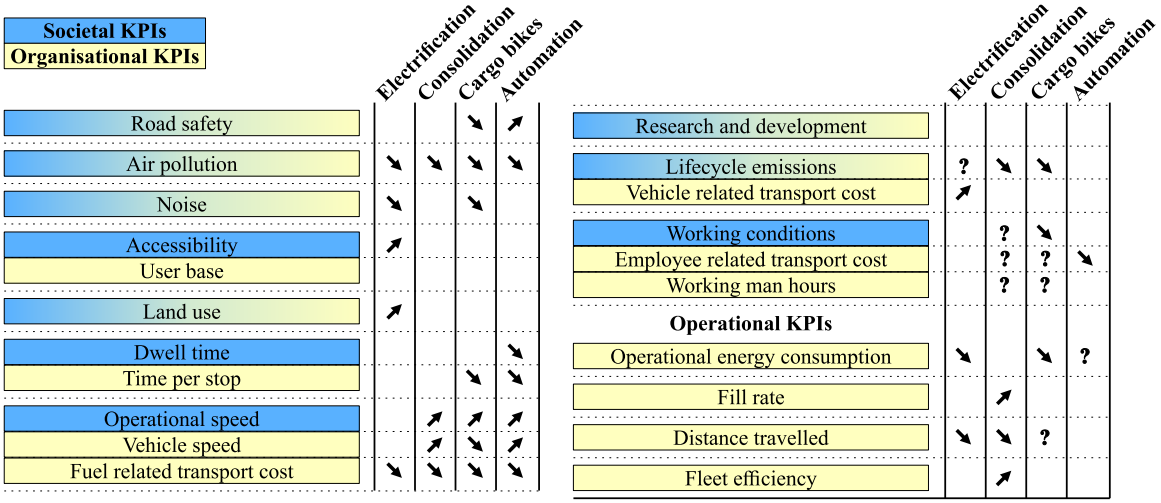

Figure 2: The SPA matrix contains the results of the sustainability performance assessment of electrification, consolidation, cargo bikes and automation. For each of these four practices, the impacts on the current urban logistics system for each KPI are represented with different symbols. ↗ means that the KPI increases, ↘ means that the KPI decreases, **?** means that the results are uncertain, while an empty space means that there are no references to the KPI in the analysed literature.

- From the SPA matrix, it can be seen that aspects of sustainability such as accessibility, working conditions and land use are not analysed extensively: there is a gap in the literature in taking a more holistic approach when analysing sustainability.
- From the SPA matrix, it can be also seen that all concepts require an investment in the infrastructure. This can lead to time delays as the change in infrastructure can be slow. This suggests the need of modelling the effect of the changes in the system using a dynamic model, that allows these changes over time to be seen and time delays to be accounted for.

Connection to the research questions and goals. Paper III addresses mainly RQ2. The set of indicators defined in Paper II is used for assessing urban logistics practices, verifying that such a methodology can be utilized (RQ2a). The paper illustrates that the aspects defined in Paper II can be used to evaluate sustainability (RQ2b). Paper III targets partially RQ3a, by understanding what parameters are important to use and monitor when modelling how different urban logistics practices impact the urban freight transport system.

4.4 Paper IV: Exploring city hubs by using a qualitative system dynamics approach

Main content. The focus of Paper III is consolidation, and more specifically, city hubs, which can reduce congestion and pollution through increased consolidation and a shift to less carbon-intensive vehicles. However, their implementation faces barriers and challenges, which often hinder their scale-up. A group model building workshop and a set of interviews are used as qualitative methodologies for data collection, together with a literature search, to build a qualitative system dynamics model that uncovers the structure of the urban freight transport system and the mechanisms behind the barriers of consolidation.

Main results and takeaways:

- The system can be described using a Causal Loop Diagram which is the main result of this work, that can be seen in Figure 3, together with the narrative of the model, i.e., the main dynamics in the system.
- The group model building workshop allows different actors and stakeholders in the system to share insights on how they perceive the system structure (i.e., insights from different perspectives). This is important since often different stakeholders and actor perceive the system differently.
- The group model building workshop also enables the different actors and stakeholders in the system to learn a new tool (i.e., system dynamics), which they can use in the future to explore other dynamic problems.
- From the interviews, it emerges that there are three main barriers for the implementation of city hubs: competitiveness of the market, difficulty of the actors and stakeholders to see benefits, and the importance of branding of the vehicles and drivers.

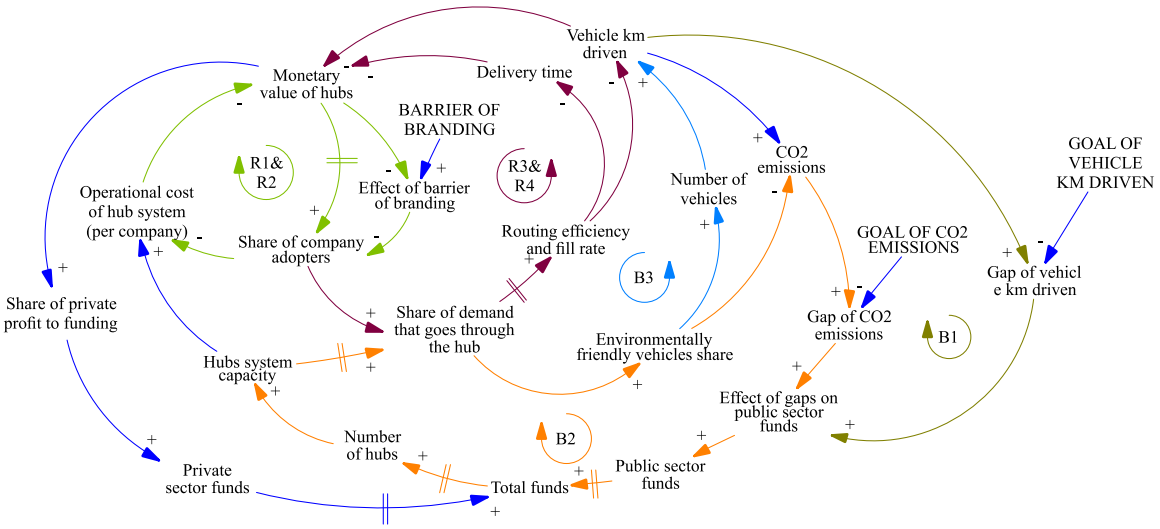

Figure 3: Causal Loop Diagram that represents the structure of an urban freight transport system. The narrative of the model is the following. Two goals are set from the public sector: to reduce CO_2 emissions and vehicle km (as a measurement of congestion) to a certain level. Therefore, two corresponding gaps are identified, by comparing the goals with the current state of the system. The public sector, knowing that city hubs can help achieve these goals, allocates funds to build a city hub system. This system is adopted by a share of the total number of transport companies. If deliveries that go through the city hub system are cheaper than the ones that do not go through the system, companies are incentivized to join. Therefore, a monetary value is associated with joining the city hub system. This value can be positive or negative, and it depends on the extent to which the city hub system increases efficiency, and on the cost associated with operations. If the value is negative, policies or regulations need to be in place for the city hub system to gain company adopters.

Connection to the research questions and goals. Paper IV addresses primarily RQ3. The Causal Loop Diagram enables an understanding (at least at a qualitative level) of how to model the effects of the introduction of city hubs in an urban freight transport system. The set of indicators (from Paper II) is used to understand what parameters are important to be considered in assessing the sustainability of the urban freight transport system. The workshops and interviews with stakeholders and actors in the system are also used to consider these indicators in the context of consolidation (RQ4a). The Causal Loop Diagram enables the understanding of the dynamics that should be considered in the case of implementation of city hubs in the urban freight transport system (RQ4b).

5 Discussion

5.1 Mapping of the research questions and the papers

Table 1 shows the research questions and subquestions (summarized with their key words) and how the papers address them. As it can be seen, Paper I targets mostly RQ4 as it is connected specifically with COVID-19 as an example of a change in the urban freight transport system. Paper II can be seen as a methodological paper that spans across multiple questions, answering RQ1 but partly also RQ2 and RQ3. Paper III involves the application of the methodology described in Paper II and therefore answers more in detail RQ2. Paper IV is a modelling paper and therefore answers only RQ4. No question remains unanswered; however, more research will be done expanding the answers to all questions, but especially RQ3.

Question	Subquestion	Paper I	Paper II	Paper III	Paper IV
RQ1 - Sustainability	RQ1a - Indicators		x		
	RQ1b - Actors and stakeholders		x		
	RQ1c - SDGs		x		
RQ2 - Practices	RQ2a - How?		x	x	
	RQ2b - What matters?		x	x	
	RQ2c - Most common practices			x	
RQ3 - Modelling	RQ3a - Parameters		x	x	x
	RQ3b - Dynamics				x
RQ4 - COVID 19	RQ4a - Effects	x			
	RQ4b - Policies	x			

Table 1: The research questions are summarized with their subquestions (see Section 2 - Research goal and questions) and are connected to the papers

5.2 Answer to research questions

RQ1: *How can the sustainability of the urban freight transport system be measured?*

(a) What indicators are suitable to be used for assessing sustainability in the urban freight transport system?

A list of indicators is identified in Paper II (Figure 1). This list can be used for assessing sustainability in the urban freight transport system, as it is derived from the SDGs which provide a holistic perspective of sustainability.

(b) How can perspectives of different actors and stakeholders be considered when assessing sustainability?

The perspectives of actors and stakeholders can be considered by defining the indicators used for assessing sustainability differently. The list of indicators identified in Paper II contains indicators defined from the perspective of both the citizen as stakeholders and the LSPs as actors.

(c) How can an urban freight transport system be designed so that it contributes towards the SDGs?

The fist step towards designing an urban freight transport system so that it contributes towards the SDGs is to understand how the urban logistics practices impact the SDG indicators. The list of indicators identified in Paper II uses the SDGs as a starting point, and therefore the effects on the SDGs can be seen by using this list.

RQ2: *What urban logistics practices would lead to a sustainable urban freight transport system?*

(a) How can the sustainability of urban logistics practices be assessed?

One way of assessing the sustainability of urban logistics practices is to use the results in the literature (including case studies and projects) as input to the list of indicators defined in Paper II. This has been done in Paper III and Report I, resulting in a qualitative comparison of different urban logistics practices in terms of sustainability performance.

(b) What aspects are needed to evaluate their sustainability?

In this work, the aspects connected to the list of indicators defined in Paper II are considered. In Paper III, these aspects are proven to be useable to assess sustainability performance.

(c) What are the most common urban logistics practices and how do they perform in terms of sustainability?

Among the most common urban logistics practices there are electrification, consolidation, cargo bikes and automation. These practices are assessed in terms of sustainability performance in Paper III, as Figure 2 shows.

RQ3: *How can the impacts of the changes in the urban freight transport system be modelled?*

(a) What parameters are the most important when modelling an urban delivery system to capture these changes?

In this work, city hubs are taken as a focus as a urban logistics practice. Regarding this practice, the most important parameters are summarized in the Causal Loop Diagram in Figure 3. These have been derived both from the list of indicators (identified in Paper II) and the qualitative data collection methodologies (described in Paper IV).

(b) What are the main dynamics that should be considered in an urban delivery system?

The main dynamics, when considering the implementation of city hubs, involve the environmental and social aspect on the one side (i.e., how the city hubs can reduce the vehicle km driven and CO_2 emissions by increasing the routing efficiency and fill rate) and the monetary aspect on the other side (i.e., how the city hubs add an operational cost variable in the system but potentially reduce other costs by increasing routing efficiency and fill rate).

RQ4: *How did COVID-19 affect the urban freight transport system?*

(a) What are the effects of COVID-19 on the urban freight transport system due to the change in behaviour of people and companies?

The effects of COVID-19 on the behaviour of people in terms of e-commerce are studied in Paper I. For example, in Italy, there has been a larger increase in online shopping during the pandemic compared to Sweden.

(b) What should be considered by policy-makers when designing policies to mitigate these effects?

As the household structure influenced the change in behaviour of people in different ways (e.g., having elderly members in the households impacted the precautions that the other members in the household took), there is a need for different policy strategies that help citizens comply with pandemic-related measures.

5.3 Methodology discussion

System thinking, as mentioned in the Introduction, is used in this research as a paradigm to understand the impacts of different changes in the urban freight transport system from a sustainability perspective. System thinking refers to the *"capability of identifying and understanding systems, predicting their behaviors, and devising modifications to them in order to produce desired effects"* (Anderson et al., 2005). A system thinking lens is especially useful when the focus is on sustainability (Williams et al., 2017). In the urban freight transport system, there is a need of a holistic view of the impacts of changes in the system, not only considering environmental aspects but sustainability as a whole. Throughout the research, different methods were applied, while keeping sustainability in focus and having a systemic view.

In Paper I, the methodology used was multivariate statistical analysis, including linear and binary logistic regressions and multinomial logit models. The input for the analysis was a online questionnaire. The survey was circulated on social media platforms and through the researchers' networks, with the focus on obtaining quick responses. Due to this focus, the survey sample (in total 530 responses from both Italy and Sweden) does not correspond exactly with the national statistics (e.g., it has a higher education level and a lower unemployment rate compared with the corresponding statistics). Moreover, differences of policies between sub-periods of the pandemic are not accounted for. Nonetheless, the analysis of the survey made it possible to highlight that different socio-demographic and household structures matter in determining the change of behaviour and should be considered when making policies. Therefore, online surveys and statistical analysis are seen as a successful possible way to investigate behavioral change.

In Paper II, Paper III and Report I the main source of information was collected through the literature and through qualitative data collection within different research projects. The literature was used to investigate what has been done previously and identify possible research gaps. The literature on sustainability in urban logistics confirms that there is a need of viewing sustainability from a holistic perspective (Gudmundsson et al., 2016) and of considering different actors' and stakeholders' perspectives (Ballantyne et al., 2013). The set of indicators proposed in this work is one step towards making a comprehensive framework that would allow different practices to be compared in terms of sustainability. However, the set of indicators needs to be utilized and validated. In this research, the method has been validated in Paper III and Report I by using it to assess some urban logistics practices which appear in the literature, by evaluating assess different case studies in the literature of logistics. However, another type of validation can be carried out by using the set of indicators for sustainability assessment in a real case study. This is planned as future work.

The Sustainable Development Goals (SDGs) (UN, 2021) are used as a starting point for the creation of the set of indicators in Paper II. It appears that it is possible to use the SDGs as a general framework to understand what needs to be considered when discussing sustainability. However, the SDGs do not include all impacts of the transportation system. Comparing the SDGs with the list of transportation externalities provided in Gudmundsson et al. (2016), it can bee seen that some of the externalities are missing in the SDGs. For example, neither noise nor congestion are targeted by the SDGs. Therefore, it was helpful to use the literature of transportation and logistics as a complement for these missing externalities that otherwise would be omitted by looking only at the SDGs.

In Paper IV, the system dynamics method is applied. The system thinking lens enables the understanding of the relations and functions of the elements within the overall system (Sterman, 2001). System dynamics is proposed as a concrete modeling method, to move from the understanding of the structure of a system to a model representation. In this research, system dynamics is used as a qualitative modelling method at first. A Causal Loop Diagram is formulated, that allows the dynamics of the system and the causal relationships between the elements of the system to be understood. The Causal Loop Diagram is translated to a stock and flow diagram, to make the model quantitative. The stock and flow structure is also included to ensure that the model structure is sound and to be able to represent delays in the system. This is a first step towards a quantitative model. However, the model is not validated in terms of values but only in terms of structure. The parameter estimation and validation of the model is part of future work.

As the modelling was done mainly to a qualitative extent, different methods of qualitative data collection were used. First, a group model building workshop was carried out. This was done to understand the problem from different perspectives and include representatives from different actors' and stakeholders' groups in the modelling process. As output of the workshop, a series of interesting causal links was derived. By putting together these links with other sources in the literature (from Paper III and Report I), a Causal Loop Diagram was created. Second, semi-structured interviews were carried out to validate the structure of the Causal Loop Diagram. Throughout this process, a high level of engagement and communication with the actors and stakeholders was required. Therefore, an expert group was created. This was helpful for the researchers in the team, that were able to gain insights from expert group, and to the expert group itself, since the people part of it gained new insights from the discussion and from the methods presented (i.e., system thinking and system dynamics).

5.4 Challenges and limitations

Various challenges were encountered during this research. First of all, the analysed problem is a sustainability problem, which is everyone's problem (i.e., everyone is suffering from sustainability related issues such as climate change and social issues) but no one feels the responsibility for it (i.e., no actor or stakeholder in the system wants to pay the economic cost for the required shift towards a more sustainable system). Connected to this problem is that in the system there are many different actors and stakeholders with diverse agendas, which are difficult to coordinate. Moreover, in the logistics system there is an acknowledged lack of data sharing. As the market is very competitive, companies are reluctant to share data. This makes it hard for researchers to understand how the system is performing today, and to have an idea of how different urban logistics practices could impact the sustainability of the system.

One limitation of this work is its applicability to other context. Transferability of urban transport practices is a topic in itself and has been studied in the literature, for example in Macário and Marques (2008) and Reda et al. (2020). As the urban freight transport system is a complex system involving different stakeholders and actors, urban logistic practices can have different impacts depending on the context that they are applied to. Therefore, their successful implementation (i.e., implementation that would increase the sustainability of the system) is not necessarily transferable between different cities. Examples of characteristics that could hinder transferability are the economic development, geographical location and context, existing issues (e.g., traffic conditions, air pollution), institutional context (Macário and Marques, 2008; Reda et al., 2020).

6 Future Work

The future work is mainly divided into two streams. The first stream is related to the sustainability of the urban freight transport system, and continuing the work done in Paper II, Paper III and Report I. A validation of the list of indicators developed in Paper II is planned, to use the indicators in a real case study. Through this type of validation, the list of indicators will be assessed in terms of usability and will be updated if necessary. Moreover, a more detailed understanding of how new urban logistics practices can be scaled up, and how does this scaling up affect the sustainability of the system, is needed.

The second stream is related to the development and expansion of the system dynamics model. The next step regarding the model work will be to acquire the needed input data to estimate and validate the parameters in the model. A possibility for acquiring the needed input data for the model is to use the output from micro-level simulations, which could be an interesting combination of modelling techniques. Different types of validations are needed, to understand if the model is a good enough representation of reality. The validated model will be then used to perform scenario analysis and help decision makers from both the public and private sector make decisions to shift the urban logistics system towards a more sustainable one. Moreover, it will enable the understanding of leverage points in the system, which will in turn enable a better understanding of the dynamics of the system and are considered important knowledge for decision makers.

To the research questions reported in the Introduction, some research subquestions are added, together with a fifth question about the usage of the model.

RQ2: *What urban logistics practices would lead to a sustainable urban freight transport system?*

(d) What parameters should be considered when testing a concept?

(e) Once the concepts are tested to be sustainable, how can these be scaled up, preserving their sustainability aspect?

RQ3: *How can the impacts of the changes in the urban freight transport system be modelled?*

(d) How should the model be set up to account for the main dynamics that should be considered in the system?

(e) What types of validation should be performed? And how?

(f) How can the knowledge from microlevel simulations be interpreted and used as a test to understand if a higher-level model is a good representation of the whole system?

RQ5: *How can a system dynamics model be used with actors and stakeholders in the urban freight transport system?*

(a) What are the leverage points in the system to improve the system in terms of sustainability?

(b) What scenarios should be defined in the case of urban logistics practices? And how?

(c) How can the scenarios help decision makers to make decisions towards a more sustainable urban freight transport system?

(d) What techniques should be used for communication and interaction with stakeholders and actors? I.e., group model building workshop, presentations, etc.

7 Conclusion

In this research, the impacts of changes on the sustainability of the urban freight transport system are studied, through survey, interview methodologies and system dynamics modelling. The main results of this work are the following. First, a list of indicators for sustainability performance assessment (Figure 1) was identified. Second, by using the list of indicators, the urban logistic practices of electrification, consolidation, cargo bikes and automation were evaluated in terms of sustainability performance (resulting in Figure 2). Third, with focus on consolidation as a sustainable urban logistics practice, a qualitative system dynamics model was developed (Figure 3). COVID-19 was also studied as an example of how an unexpected change can disrupt the transport system and impact the urban freight transport system as well as the behaviour of people and companies.

The main findings of this research therefore are the following:

- The SDGs can be used as a starting point to derive indicators for sustainability performance assessment.
- However, the SDGs are not complete, as in they do not consider the impacts all the transportation externalities. Therefore, the context of transportation and logistics needs to be also considered.
- The set of indicators defined in Paper II can be used to holistically analyse how different urban logistics practices perform in terms of sustainability and compare their impacts.
- The system thinking lens helps to keep a system level view of the impacts and it is useful to study sustainability.
- The system dynamics methodology can be used to understand how different actors and stakeholders perceive the urban freight transport system and its structure. This enables the modeler to consider different perspectives when modeling the system.

In the future work, one stream of research will focus on the sustainability aspect, with the validation of the indicators defined in Paper II. The second stream will focus on the development of the system dynamics model, with validation of the parameters and sensitivity testing. The main goal of the usage of the model is to enable actors and stakeholders in the system to see the leverage points in the system and to help them make decisions that shift the urban freight transport system towards a more sustainable one.

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