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Analysis of interrelationships among key factors of smart urban logistics and urban access management: a system dynamics-based model

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Abstract

In response to urbanization and digitalization, smart urban logistics (SUL) play a crucial role in managing city goods, alleviating congestion, and reducing pollution. The COVID-19 pandemic has heightened e-commerce, highlighting challenges in last-mile delivery such as traffic congestion and carbon emissions. This study aims to improve the understanding of the effects of strategies for urban logistics access management to enhance the efficiency, safety, and sustainability of goods, vehicles, and people in urban environments. The primary goal of SUL is to create an integrated urban logistics ecosystem where goods are delivered efficiently and sustainably, reducing environmental impact and improving city life. This article presents a System Dynamics (SD)-based model to investigate the intricate interplay of key factors influencing SUL and urban access management. By highlighting these interconnections, it elucidates which strategies can effectively manage urban freight traffic within sustainable urban development and emphasizes how these efforts contribute to achieving the objectives of the 2030 Agenda. The contribution of this work lies in its comprehensive analysis of urban logistics dynamics, offering insights into urban access management protocols, dynamic parking organization, and incentives for electric or human-powered vehicles. These measures align with the 2030 Agenda, promoting safer, cleaner, and more accessible urban mobility.

Keywords: Access management, Sustainability, System dynamics, Logistics strategy, Smart urban logistics

1. Introduction

Urban logistics faces a myriad of challenges in modern cities, necessitating innovative solutions for efficient and sustainable transportation. Traffic congestion, a prevalent issue in densely populated urban areas, leads to delivery delays and worsens air pollution, impacting public health. Limited road accessibility exacerbates logistical difficulties, impeding delivery routes and increasing operational costs. Safety concerns arise due to heavy traffic, posing risks to both drivers and pedestrians. Additionally, urban logistics significantly contributes to environmental degradation through greenhouse gas emissions, necessitating the adoption of low-emission vehicles and sustainable delivery practices to mitigate its impact on climate change. The COVID-19 pandemic has aggravated urban logistics challenges by significantly increasing online commerce and demand for delivery services. This surge has intensified traffic congestion and pollution, revealing the limitations of current logistics infrastructure and underscoring the need for more resilient and adaptive systems (Baldrighi et al., 2023). In this context, Smart Urban Logistic (SUL) system modeling (Büyüközkan & Ilıcak, 2022) and urban access management can play a significant role in achieving the goals of the 2030 Agenda (United Nations, 2015), contributing to promoting sustainable and inclusive urban growth. Integrating these objectives into research and development strategies in the field of smart urban logistics becomes essential to ensure a fairer, more resilient, and sustainable urban future by 2030. The academic community has focused on exploring the topic of smart urban logistics, supporting institutions in the process of introducing measures to improve freight transportation in urban and metropolitan areas, while simultaneously aiming to reduce the negative externalities, like environmental and social impacts. On one hand, the European Union has promoted the adoption of sustainable logistics practices (European Commission, 2013), and on the other hand, it has implemented projects to classify and organize the various initiatives carried out by individual cities, aiming to have a systemic view of intervention types and their effects. Of particular interest for the proposed model is the ReVeAL project, which focuses on measures for regulating access of urban vehicles (Civitas, 2022) in order to empower cities to enhance the utilization of urban space and transportation networks by implementing innovative packages of urban vehicle access policies and technologies. The ReVeAL project introduces three primary mechanisms for implementing Urban Vehicle Access Regulations (UVAR) (Fransen et al., 2023), referred to as "Measure Fields". These Measure Fields encompass various aspects, further categorized into Building Blocks (Fransen, Koos, 2018), which include:

- Spatial interventions: this involves altering road layouts to prioritize sustainable mobility and restrict vehicle access. Examples include repurposing road and parking space for sustainable mobility options.
- Pricing aspects: these mechanisms introduce pricing measures to incentivize sustainable transport choices, such as implementing road charges based on factors like congestion, distance traveled, or emission standards.
- Regulatory measures: this involves implementing legal instruments to control access to specific areas. Examples include Zero Emission Zones, Low Emission Zones, Limited Traffic Zones, and regulations based on emissions standards, vehicle types and dimensions, trip purposes, or permits.

A Zero-emission Zone (ZEZ) is a designated area where only vehicles that produce zero emissions are allowed to enter. A Limited Traffic Zone (LTZ) (or Traffic-limited zone) is a defined spatial area characterized by low traffic volume, typically resulting from access regulations implemented by the local municipality. While a Low-Emission-Zone (LEZ) is an area where vehicular access is limited to vehicles that meet certain emissions characteristics. According to the ReVeAL project, the various building blocks within this regulating measure field are the components that can be combined to form a comprehensive UVAR scheme. These include:

- Regulations by emissions: Brussels, Belgium, mandates that only vehicles meeting specific emission standards can enter certain areas (Times, 2023);
- Regulations by vehicle type and dimension: Paris, France, focuses on regulating vehicle entry based on their types, restricting access for specific categories of vehicles (Feargus O'Sullivan, 2017); Utrecht, The Netherlands, distinguishes between Heavy Duty Vehicles (HDV) and Light Duty Vehicles (LDV), enforcing regulations based on their dimensions (Bhoraskar A. & Mulder J., 2023);
- Regulations by trip purpose: Strasbourg, France, tailors regulations based on trip purposes, particularly targeting delivery vehicles (Civitas ReVeAL, n.d.);
- Scheme timescale: Madrid, Spain, enforces regulatory schemes within specific time windows (Ibid.); Stockholm, Sweden, implements time-based regulations, focusing on night-time restrictions (City of Stockholm, 2019);
- Regulations by permit: Siena, Italy, requires a travel permit for vehicle access (Maggi, 2016); London, United Kingdom, regulates vehicle access based on planning permits (Transport for London, 2017);
- Regulations by other: Load factor; Vehicle safety features; Company size; Removing road space.

Various scales necessitate distinct solutions for urban logistics measures, and these solutions are usually integrated into Sustainable Urban Logistics Plans (SULPs). The UVAR measures offer several benefits, including reduction of air pollution, improvement of air quality, promotion of sustainable mobility, and traffic reduction. However, they can also present some drawbacks, such as negative economic impacts, limitations on freedom of movement, potential unintended side effects, and implementation challenges. UVAR measures can incur costs for businesses (e.g., purchasing/retrofitting vehicles to meet standards, obtaining permits, paying taxes or fines for non-compliance). To mitigate these negative impacts, incentives for fleet renewal have been introduced. Also, the European Parliament (2023) emphasizes urban mobility's vital role in improving citizens' quality of life and supporting economic efficiency. It calls for smart, accessible, affordable, and integrated transport systems. Regarding UVAR, the resolution stresses the necessity for thorough impact assessments and public consultations. It highlights the importance of transparent information dissemination and notifying all stakeholders about economic considerations. Also managing parking spaces for loading operations poses significant challenges to urban traffic performance. Firstly, on-street parking occupies road space, reducing traffic capacity on the road and adjacent networks. Secondly, parking and unparking maneuvers create temporary traffic bottlenecks, resulting in increased travel time. Thirdly, specific parking behaviors, such as illegal parking or loading/unloading by trucks or buses, diminish road capacity and cause inconvenience and confusion for other travelers (Roca-Riu et al., 2017). The present model will incorporate dynamic parking management measures, utilizing technologies and policies to regulate parking spaces based on demand and other factors. This approach aims to optimize parking utilization by dynamically adjusting factors such as pricing, availability, and time restrictions. Implemented through time-based regulations or real-time Intelligent Transportation Systems (ITS), dynamic parking management alleviates congestion, enhances traffic flow, and improves urban parking system efficiency. It benefits urban logistics by efficiently utilizing loading and unloading areas, reducing wait times, and enhancing delivery planning. Moreover, it promotes turnover of commercial vehicles, increasing accessibility to loading spaces for a broader range of operators. However, there are also challenges to consider: implementing dynamic parking management systems can involve high costs for investments in technology and infrastructure. Moreover, it may require close collaboration between public and private entities to ensure effective management and maintenance of the systems.

This article delves into the intricate web of interrelationships among key factors shaping SUL and urban access management, with a focus on elucidating a systematic approach through a System Dynamics (SD)-based model. The central query driving this investigation is: what strategies can effectively harmonize the burgeoning demands of urban freight traffic with the imperative of sustainable urban development? Our findings underscore that optimizing fleet composition, integrating electric or hybrid vehicles and human-powered (HP) or assisted vehicles (AV) for proximity deliveries, is crucial for balancing urban freight demands with sustainable development. Using a System Dynamics (SD) model, we highlighted how altering fleet composition impacts emissions reduction, traffic congestion, and operational efficiency, making it a pivotal strategy for policymakers. Strategies such as access management, incentives for cleaner technologies, and improved urban space management can influence fleet composition. However, not all strategies achieve desired outcomes; for instance, while switching to electric vehicles reduces emissions, it may not alleviate congestion. This complexity necessitates comprehensive approaches addressing multiple sustainability dimensions, enhancing environmental sustainability and urban resource management efficiency. Providing the basis for subsequent in-depth analysis based on a Stock and Flow quantitative model, this study aims to improve the understanding of the short- and long-term effects generated on the system by the introduction of certain Smart Urban Logistics measures (such as access management interventions, incentives for purchasing alternative vehicles, and dynamic parking management). Practical implications include providing urban planners and policymakers with a framework to implement sustainable logistics solutions and improve overall urban mobility. These solutions, composed of a mix of various elements, aim to not only meet the current demands of urban freight traffic but also align with the long-term objectives of the 2030 Agenda for sustainable development. In Section 2, through a comprehensive examination of the State of the Art in access management definition and SD modeling for SUL systems, the study navigates through various access management options, offering insights into their efficacy and implications. In Section 3, drawing from a meticulous analysis, the article identifies the pivotal parameters and variables influencing freight traffic dynamics within urban landscapes. By delineating clear objectives for urban administration, the study delineates pathways through which access management regulations or policies can be tailored to achieve these goals effectively. The presentation of a causal loop diagram (CLD), a visual representation aimed at unraveling the intricate interdependencies and feedback loops inherent in SUL systems, is proposed. In Section 4, by illuminating these complex relationships, the model provides a roadmap to navigate the nuanced terrain of urban logistics and access management, fostering sustainable urban development while mitigating logistical challenges.

2. State of the art

Urban logistics plays an increasingly important role in modern cities, where efficient transportation management is essential to ensure residents' well-being, support economic development, and mitigate the negative impacts of transportation (Büyüközkan & Ilıcak, 2022). One of the main challenges is minimizing the adverse effects of transportation, including traffic congestion, air and noise pollution, as well as environmental impact from greenhouse gas emissions. Addressing these challenges requires the adoption of innovative policies and strategies, such as promoting sustainable transportation modes, optimizing delivery routes, and introducing low-emission vehicles. Various classifications of measures to improve urban logistics have been proposed. Merchan and Blanco (2015) proposed categorizing best practices into four areas: Urban Logistics Spaces for Multi-Tier Last-Mile Distribution, Emerging Vehicles for Last-Mile Distribution, Complementary Last-Mile Distribution Strategies, and Additional Technologies. The first category encompasses Urban Consolidation/Transfer Centers, Micro-deconsolidation Platforms, Micro-consolidation Platforms, Delivery Bays, and Automatic Parcel Terminals. In the second category, solutions involving the use of alternative vehicles are included, such as Cargo-cycles, Electric Trucks, Mobile Warehouses, and Autonomous and Semi-autonomous Vehicles. The third category comprises complementary measures, including Off-hour Deliveries, On-demand (Crowd-sourced) Last-mile Services, and Last-Mile Delivery using the Bus Rapid Transit/Subway System. Finally, the last category includes technological solutions such as GPS Sensors and Data for Logistics. De Marco et al. (2018) divided the measures of City logistics into: Infrastructure, Regulation and Technology. In addition to classifying the various measures aimed at improving urban logistics, research has also focused on analyzing the optimal way to combine interventions according to the institutional entities responsible for identifying and implementing these measures within their strategic plans (Macário et al., 2023). While this research typically adopts a more general approach, there are numerous studies centered on specific measures, aiming to optimize their implementation or test their outcomes, such as those focused on Zero Emission Zone (Cui et al., 2021) or Low Emission Zone (Ceccato et al., 2024). Simulation is relevant in the field of logistics, enabling to analyse, optimize, and plan logistics strategies and operations more effectively. There are three primary approaches of simulation used in this domain: discrete event simulation, agent-based simulation, and SD (Borshchev & Filippov, 2004). Discrete event simulation models the logistics system as a series of discrete events that occur over time. Each event represents a change in the system's state, such as the arrival of a vehicle, the loading or unloading of goods, or the completion of a delivery. This type of simulation is particularly useful for analysing complex systems where events occur non-continuously and for studying the interactions between different logistics components, such as warehouses (Bottani et al., 2020), unloading infrastructure (Voegl et al., 2019), vehicles, and distribution centers, also integrating material elements equipped with sensors and immaterial elements, as in the case of digital twins (Agalianos et al., 2020). It helps in identifying bottlenecks, optimizing resource allocation, and improving process efficiency. Agent-based simulation models the system through the interaction of autonomous agents, each with its own behaviours and objectives. Agents can represent various elements of the logistics chain, such as vehicles, operators, customers, or even infrastructure. This approach is useful for studying the emergent behaviour resulting from the interaction of multiple agents and for evaluating the impact of logistics management policies on both local and global scales. For example, it can be used to simulate the behaviour of trucks drivers in response to different traffic policies or toll charges or decision processes of the different nodes in a supply chain (Keramydas et al., 2016). SD simulation focuses on the feedback loops and time delays that affect the behaviour of the entire logistics system. It uses stock and flow diagrams to model complex interactions within the system and to understand how different components influence one another over time. This type of simulation is particularly valuable for strategic planning and policy analysis, as it helps in identifying leverage points and predicting the long-term impact of different logistics strategies, but also for companies in order to improve activities, like for example supply chain management (Mutanov et al., 2020). SD is ideal for examining how changes in one part of the system can ripple through and affect the whole, making it a powerful tool for addressing systemic issues in logistics. It is especially useful for understanding the broader implications of policy decisions and for developing sustainable logistics practices. Studying transportation and urban logistics with a SD approach is crucial for a comprehensive understanding of complex urban logistics systems. It allows researchers to model various factors like vehicle fleets, traffic flow, and access management, revealing dynamic system behaviours over time. Moreover, this approach enables long-term impact assessments of policy interventions and logistical strategies, aiding decision-makers in formulating effective urban logistics policies. Additionally, these models help identify synergies and trade-offs between policy objectives, enabling policymakers to make informed decisions that balance competing priorities. Furthermore, delving into causal loops within the SD models provides valuable insights into the interconnectedness of variables, aiding in understanding the underlying causes of system behaviours and identifying leverage points for policy interventions (Mandl, 2019). An example of this is the SD model that examines the intricate relationship between logistics strategies and freight transport (Aschauer et al., 2015).

3. Materials and Methods

Drawing upon insights gleaned from existing literature, a model boundary chart was formulated to delineate the observed parameters (Sterman, 2000) In total, 45 parameters were discerned as pertinent to the investigation into smart urban logistics and urban access management. Subsequently, these parameters underwent classification into endogenous (those influenced by and influencing other parameters), exogenous (those influencing endogenous parameters but not influenced by others), and excluded (parameters not yet incorporated into the SD model), as illustrated in Table 1. Following the boundary clarification process, the causal diagram was constructed.

The causal loop diagram (CLD) represents the major feedback mechanisms and serves as a simplified representation of the model. The first step of our analysis is to capture the relationships among the system operations in an SD manner and to construct the appropriate causal loop diagram. We will delve into the details of the presented CLD by proceeding from the general to the specific.

Table 1 Model boundary chart

Endogenous	Exogenous	Excluded	Outcome 2030 Agenda
Order Cycle frequency/ Amount per order cycle/	Production Amount	Logistic concept	SDG 7 Affordable and clean energy
Shipment amount/Load factor/Capacity of traditional/alternative trucks/N. of transports/ Portion of alternative vehicles/N. of km travelled by traditional/alternative vehicles/Fossil consumption	UVAR Incentives for the use of alternative vehicles	Outsourcing Delocalization Delivery failure rate	SDG 9 Buld resilient infrastructures, promote sustainable industrialization, and foster innovation
Air/Noise pollution/Transport emissions/Quality of urban life/Transport costs/N. of accesses/N. of HP/electrical/traditional accesses/Road infrastructure utilization/Level of consumption of parking areas/Space for parking areas/other uses/Optimization of urban spaces/Traffic and congestion/Road safety/Available/Effective delivery time/N. of deliveries/Productivity/Time to circulate/to park	Incentives for the use of HP/AV Dynamic Parking Areas Road capacity Available alternative vehicles	Difference online orders/in store orders	SDG 11 Make cities and human settlements inclusive, safe, resilient and sustainable SDG 15 Protect, restore and promote sustainable use of terrestrial ecosystems, sustainable manage forests, combat desertification (…)

The CLD (Figure 1) is structured into three distinct areas, each delineating crucial aspects of the study's focus. At the center lies the box titled "Company and urban interactions" which serves as the nexus for understanding the dynamics between corporate entities and the urban environment. This central area encapsulates the intricate interplay between businesses, logistics operations, and the broader urban landscape, shedding light on how these interactions influence the flow of goods and services within the city.

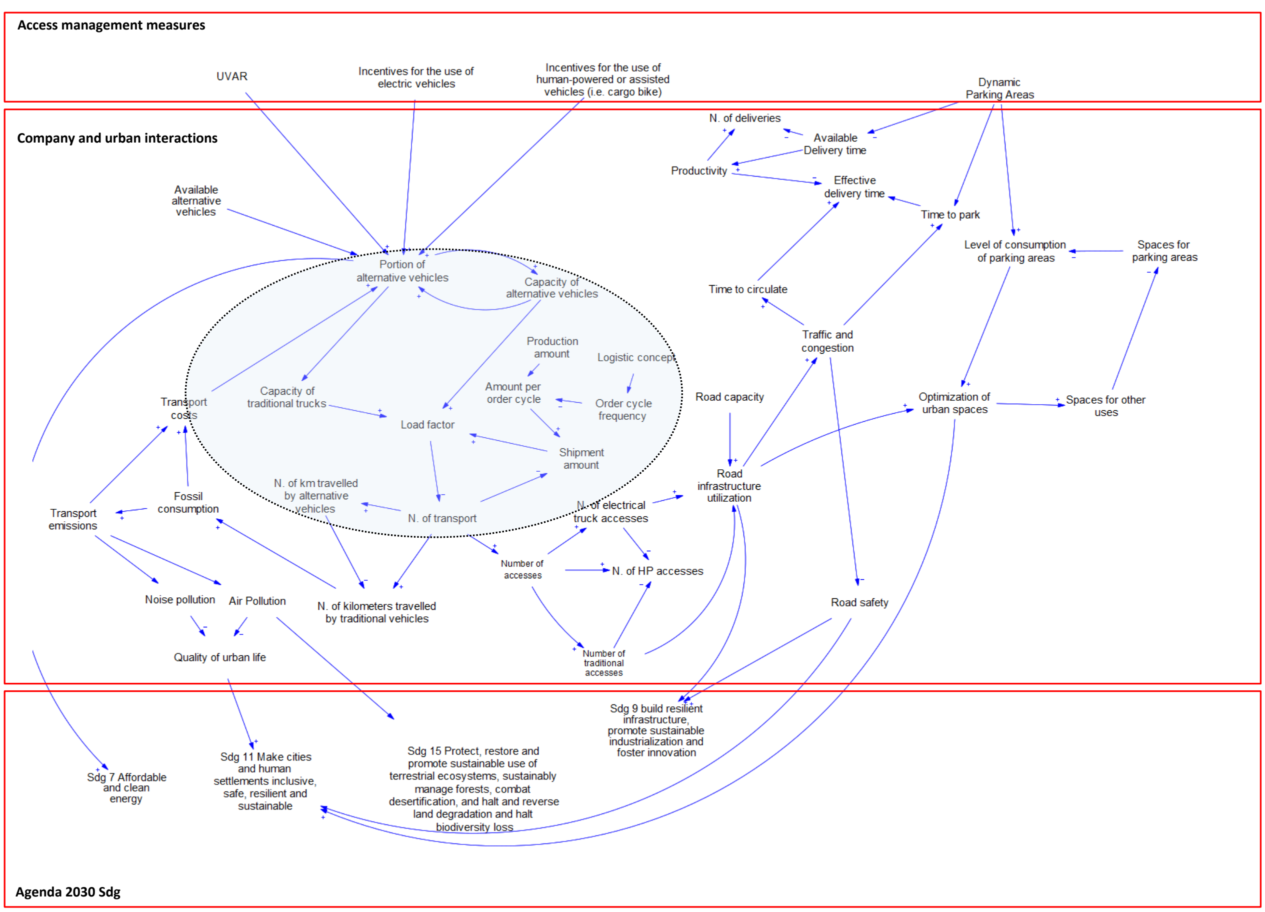

Figure 1. Causal loop diagram

Moving to the upper section, we encounter the box labeled "Access management measures", where a comprehensive array of access management measures is explored, including both restrictive and supportive interventions. Among the restrictive measures are UVAR and Dynamic parking designed to regulate and optimize traffic flow and parking within urban areas. Complementing these restrictive measures are supportive interventions such as "Incentives for the use of electrical vehicles" and "Incentives for the use of HP/AV" (i.e., cargo bike). These supportive measures aim to incentivize the adoption of environmentally friendly transportation modes, contributing to a more sustainable urban mobility landscape. In several points of the diagram, for simplicity, reference will be made to both electric vehicles and HP or AV, defining them as "alternative vehicles".

The third box "2030 Agenda Sustainable Development Goals (SDGs)" relates different types of Access Management measures, through interactions with the urban and corporate system, to some of the 2030 Agenda Goals, particularly to "Ensure access to affordable, reliable, sustainable and modern energy for all" (SDG 7 - Clean and Affordable Energy), "Build resilient infrastructure, promote inclusive and sustainable industrialization, and foster innovation" (SDG 9 - Industry, Innovation, and Infrastructure), "Make cities and human settlements inclusive, safe, resilient, and sustainable" (SDG 11 - Sustainable Cities and Communities), and "Protect, restore, and promote sustainable use of terrestrial ecosystems, sustainably manage forests, combat desertification, halt and reverse land degradation, and halt biodiversity loss" (SDG 15 - Life on Land).

4. Results and Discussion

The proposed model, examining the interrelationships among key factors of smart urban logistics and urban access management, provides a solid foundation for an in-depth discussion on implications and potential actions to be taken, offering significant benefits even in the realm of assessing the impacts of public policies. The model furnishes an analytical framework for understanding how urban access management policies and strategies influence fleet composition and urban logistics dynamics in an integrated manner. Entering into the detail of the CLD, a crucial variable in the model is the Portion of alternative vehicles (Figure 2), defined as the percentage ratio between the capacity of alternative vehicles used (such as electric vehicles and HP vehicles) compared to the total capacity of the fleet vehicles. Portion of alternative vehicles is directly influenced by three out of four of the measures studied (UVAR and incentives for alternative vehicles) and is fundamental for analyzing modal shift phenomena. The availability of vehicles and their potential capacities also affects Portion of alternative vehicles, influenced by both market factors and company constraints. Understanding how these factors interact is essential for optimizing Portion of alternative vehicles and promoting the adoption of alternative and sustainable transportation options. The Portion of alternative vehicles is directly linked to the loading capacity of both traditional and alternative vehicles. Additionally, it can be observed that the availability of vehicles with higher capacity in the market may accelerate modal shift, leading to a further increase in the presence of alternative vehicles compared to the total, but over time, a greater capacity will result in a slowdown in the Portion of alternative vehicles.

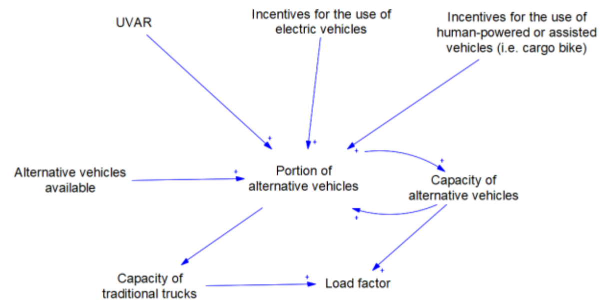

Figure 2. Interrelationships concerning fleet composition

The presence of UVAR measures affects the fleet composition, and so the Portion of alternative vehicles, by reducing the capacity of available traditional vehicles, thereby encouraging the use of alternative vehicles that could be acquired, outsourced for delivery services, or replaced with alternative vehicles. The literature identifies several types of UVAR, including emission-based regulations, vehicle type and dimension regulations, trip purpose regulations, scheme timescales, permit regulations, and other regulations. However, these various measures can be broadly categorized into two main perspectives: spatial and temporal. Spatial regulations limit access to specific areas, while temporal regulations restrict access during certain time periods, or a combination of both. In either case, the overall fleet capacity (the capacity of traditional vehicles plus the capacity of alternative vehicles) is impacted. Spatial access limitations decrease the capacity for traditional vehicles, necessitating an increase in alternative vehicles to maintain the same total capacity. On the other hand, temporal access limitations reduce capacity to zero during the restricted periods. The presence of incentives for acquiring alternative vehicles is positively correlated with Portion of alternative vehicles, potentially acting as a "multiplier" for the capacity of alternative vehicles. This is because, thanks to the incentives, new capacity can likely be acquired at a lower cost, or even halved, depending on the value of the incentives themselves. It is advisable to keep the two types of incentives separate because the different types of vehicles (whether electric or HP) impact the variables of interest in different ways. For example, electric vehicles have an impact on emissions but not on traffic. Another important part of the CLD is related to the so-called "logistic effect" through the variable "load factor (Figure 3). The "logistic effect loop", which is a reinforcing loop, comprises three parameters: shipment amount, transports, and load factor. The "load factor" refers to the ratio of the actual load carried by a vehicle, such as a truck, to its maximum load capacity. It is typically expressed as a percentage and indicates how efficiently the vehicle's capacity is being utilized. For example, if a truck is carrying 80% of its maximum load capacity, then its load factor is 80%. A higher load factor implies that the vehicle is operating closer to its full capacity, while a lower load factor suggests that there is unused capacity that could be utilized to increase efficiency.

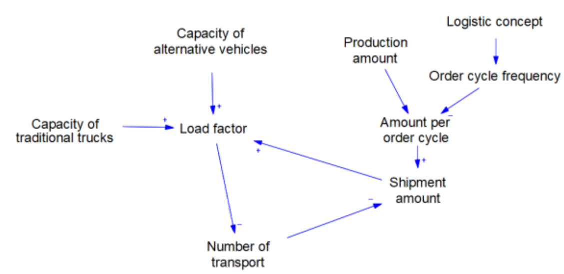

Figure 3. Logistic Effect Loop

The shipment amount is influenced *ab origine* by the adopted logistics concept (e.g., Make to stock, Make to order), which affects the order cycle frequency and amount per order cycle (this is influenced also by the production amount of the company or supply chain). A high volume of order releases implies a smaller shipment amount, and conversely, fewer order releases result in a larger shipment amount. Reduced shipment volumes correlate with lower truck utilization, while increased shipment volumes positively impact truck utilization (Kummer, 2006). The number of transports conducted has a positive impact on the distance traveled by traditional vehicles, but simultaneously, (depending on the fleet composition regarding the Portion of alternative vehicles), it generates a certain number of kilometers traveled by alternative means (Figure 4). Since these variables are complementary, the number of kilometers traveled by alternative means will have the opposite sign compared to the number of kilometers traveled by traditional means, which are responsible for noise and pollutant emissions. In fact, the decrease in the number of kilometers traveled by traditional means will result in a reduction in the use of fossil fuels, responsible for environmental and noise pollution. Therefore, we introduce the concept of "quality of life" as an index composed of a series of indicators, including those of air and noise pollution. It can thus be asserted that the reduction of vehicles powered by fossil fuels generates a positive impact on the quality of life.

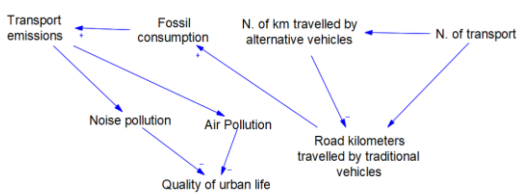

Figure 4. Interrelationships concerning fossil consumption

The section concerning "Fuel cost Loop" (Figure 5) includes several key parameters and influences. The distance traveled for transportation is affected by the percentage of utilization.

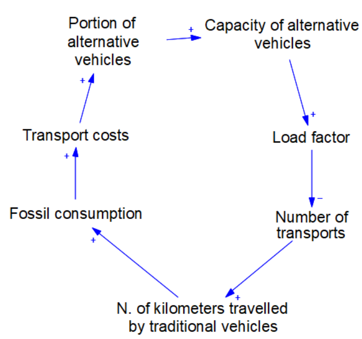

Figure 5. Fuel cost Loop

Moreover, this factor is influenced by the physical proximity between the company and its suppliers or customers. For instance, if the distance is 100 km and utilization is 100%, only 100 km are traveled. However, if utilization decreases to 50%, then 200 km must be traveled. Increased distance traveled results in higher fuel consumption, subsequently elevating transportation costs, particularly during fuel price surges due to crises or the implementation of new taxes. This not only affects the pressure for load consolidation, already analyzed in Aschauer et al. (2015) but, for the purposes of this research, it is interesting to note that it also has an impact on the change in Portion of alternative vehicles. As fossil fuel costs increase, companies will be induced to acquire alternative vehicles in their fleet. This is the result of the "Fuel cost loop", which is a balancing loop. The number of transports directly influences the number of accesses into the city for both traditional vehicles and electric and HP/AV vehicles (Figure 6).

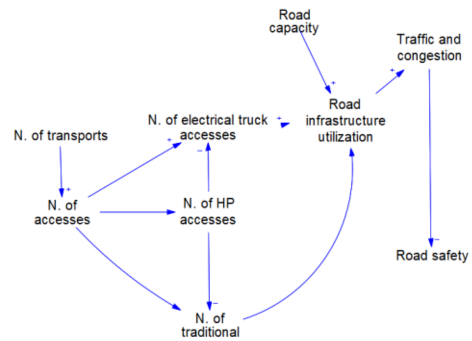

Figure 6. Number of accesses

The total number of accesses consists of entries by traditional, electric, and HP/AV vehicles. Traditional and electric vehicles have a positive impact on the utilization level of road infrastructure (characterized by a certain capacity): the more vehicles enter the city, the higher the utilization level of the roads will be. HP or AV indirectly have a traffic decongesting effect because their use replaces traditional and electric vehicles, utilizing dedicated lanes. Increased utilization of road infrastructure generates traffic, and when the infrastructure becomes saturated, congestion ensues, simultaneously increasing the number of road accidents, thus negatively impacting urban safety. The final measure under consideration refers to the establishment of dynamically utilized parking areas. The implementation of such areas entails ramifications at both the corporate and urban levels. At the urban level, we observe a reinforcing cycle pertaining to the optimization of urban spaces (Figure 7). The optimization of parking areas, facilitated by geographical constraints or temporal restrictions, engenders a heightened utilization rate of these spaces (termed as the Level of consumption of parking areas). To illustrate simplistically, envisioning urban space comprising road infrastructure, parking zones, and areas designated for alternative purposes, the reduction in parking areas precipitates an augmentation in space allocation for alternative functions. Concurrently, this reduction amplifies the Level of consumption of parking areas, thereby fostering an enhanced overall optimization of urban spaces.

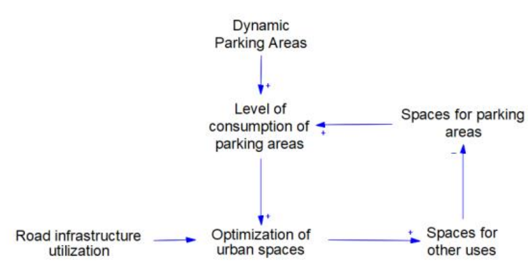

Figure 7. Urban spaces Loop

The final section of the diagram includes the interrelationship regarding the corporate productivity in terms of delivery efficiency (Figure 8). The establishment of dynamic parking areas translates into the creation of delivery time windows, resulting in a reduction of available hours for conducting deliveries. If productivity is understood as the ratio between the number of deliveries made and the time available for their execution (e.g., in terms of available hours), we can observe that the decrease in available hours is inversely related to the number of deliveries but aligned with the increase in productivity. This influences the decrease of the effective delivery time. It is well-established that the reduction in delivery time (which is nonetheless negatively influenced by traffic and congestion) confers advantages both for the company (in terms of cost reduction) and for the customer, enhancing their satisfaction.

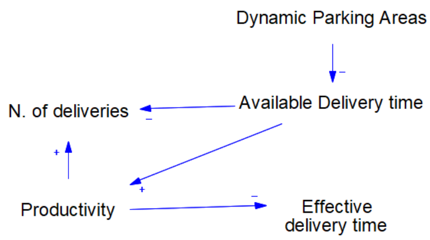

Figure 8. Interrelationship regarding Productivity

In the context of the interrelations between access management measures and urban logistics, several variables can be linked to the objectives of the United Nations' 2030 Agenda. The Portion of alternative vehicles, for example, is closely related to SDG 7, thus supporting efforts to ensure accessible, safe, sustainable, and affordable energy. The Quality of urban life, Road safety and Optimization of urban spaces are crucial variables that relate to SDG 11. Access management measures that promote the creation of more livable, safe, and inclusive urban environments can contribute to social cohesion, equity, and the sustainability of urban communities. Air pollution, often caused by vehicular traffic in cities, is directly linked to SDG 15. Reducing air pollution through access management measures can help preserve air quality and protect urban and natural ecosystems, thereby supporting the sustainable management of land resources and the conservation of biodiversity. Finally, Road safety and Optimization of urban space can be associated with SDG 9. Implementing access management policies aimed at improving road safety and optimizing infrastructure utilization can promote the sustainability and resilience of cities, as well as foster innovation in transportation and urban mobility sectors. One of the key elements is therefore fleet composition, representing by the Portion of alternative vehicles used relative to the total fleet capacity. The Portion of alternative vehicles is directly influenced by UVAR measures and incentives for purchasing alternative vehicles and is crucial for analyzing modal shift phenomena. Vehicle availability also impacts Portion of alternative vehicles, influenced by both market factors and company constraints. Understanding how these factors interact is essential for optimizing fleet composition and promoting the adoption of alternative and sustainable transportation options. Additionally, the model highlights the interconnections between various factors, such as vehicle loading capacity, and their impact on logistics efficiency and the urban environment. This deeper understanding of SD enables decision-makers to more accurately assess the effectiveness of public policies and to identify potential synergies or trade-offs between different objectives, such as reducing air pollution, enhancing road safety, and optimizing urban space. Ultimately, the model can serve as a valuable tool for informing the decision-making process and supporting the development of more effective and sustainable public policies in the context of urban logistics and access management. As a benefit, the model offers the possibility to analyze the combination of different measures in a synergistic and effective way. This integration capability could allow decision-makers to develop more comprehensive and coherent strategies to optimize urban logistics and urban access management. For example, UVAR policies can be integrated with incentives for the adoption of alternative vehicles to assess impacts on emissions, while dynamic parking management measures can be coordinated with the introduction of electric vehicles to analyze impacts on traffic or road safety. Furthermore, the combination of various measures can promote the creation of synergies, improving the overall efficiency of urban logistics and contributing to achieving sustainability and urban quality of life goals.

Although the proposed model provides valuable insights into the complexities of smart urban logistics and urban access management, it is important to acknowledge its limitations and areas for future development. One limitation lies in the complexity of the urban environment itself, which involves numerous interacting factors that may not be fully captured by the model. For example, socio-economic factors, cultural differences, and local regulations could significantly influence the effectiveness of policies and strategies related to fleet composition and access management. Furthermore, the model may not account for all possible feedback loops and nonlinear relationships within the urban system, potentially leading to an oversimplification of certain dynamics, especially since it doesn't distinguish between deliveries to stores and deliveries to end customers (last mile deliveries). Additionally, the model's predictive capabilities may be limited by uncertainties in data availability and future scenarios, especially in rapidly evolving urban environments. In terms of future developments, efforts could be made to improve the accuracy and predictive capability of the model by incorporating more detailed data. This could involve conducting empirical studies to validate the model's assumptions and refine its parameters based on real-world observations. Additionally, a quantitative stock and flow model will be developed to assess the impacts of diverse measures. Moreover, the model could be expanded to consider broader socio-economic impacts, such as job creation, economic growth, and social equity, to provide a more comprehensive understanding of the implications of urban logistics policies and access management. Additionally, in the future, the model could be integrated with other types of measures that affect city logistics, such as the creation of consolidation centers.

5. Conclusions

The proposed model provides a framework for comprehensively understanding the intricate dynamics of smart urban logistics and access management, offering invaluable insights into policy implications and effective strategies. By analyzing the interactions between various factors such as UVAR policies, fleet composition, and logistics productivity, the model empowers decision-makers to optimize urban logistics strategies with precision. Its integration capability allows for the identification of synergies between different measures, thereby enhancing the overall efficiency of urban logistics and advancing sustainability goals. While the model exhibits certain limitations, such as oversimplification of dynamics and data uncertainties, its positive impact is undeniable. Future improvements, including the incorporation of detailed data and consideration of broader socio-economic impacts and measures, promise to further enhance its accuracy and applicability. In essence, the proposed model aims to serve as the foundation for a more robust simulation model aimed at shaping more effective and sustainable urban logistics and access management policies. It seeks to integrate simulation techniques to comprehensively address the challenges of urban freight transportation. It lays the groundwork for a simulation model that can support institutions in devising effective and efficient strategies based on the following findings:

- Importance of Fleet Composition Optimization: the model integrates traditional vehicles with alternative vehicles, along with HP or AV, to reduce emissions, congestion, and enhance operational efficiency;
- Enhanced Urban Space Management and Dynamic Parking Management: restrictive measures and incentives must be complemented by strategies aimed at improving urban space management. The model proposes dynamic parking solutions

to enhance delivery efficiency and optimize parking areas by reducing congestion. This would free up space for other uses such as green areas or pedestrian zones, thereby improving quality of life.
- Public-Private Collaboration: it fosters partnerships between public and private sectors to effectively implement sustainable urban logistics policies.

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