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CHALLENGES OF LOGISTICS PROCESSES IN URBAN CONSOLIDATION CENTRES TO ENHANCE EFFICIENCY AND SUSTAINABILITY

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Abstract: *This article highlights the growing importance of Urban Consolidation Centres (UCCs) in sustainable urban logistics, offering a comprehensive literature review of their role in improving efficiency and reducing environmental impacts. Urban Consolidation Centres (UCCs) are gaining recognition as a critical solution for addressing urban freight challenges, such as congestion and pollution, by consolidating deliveries in central urban areas. The article provides an overview of key logistics planning tasks essential for UCC design and operation, including location and layout planning, routing optimization, warehouse design, and the integration of emerging mobility solutions like e-mobility and micromobility. Additionally, it explores various operational strategies, such as cross docking, consignment, and postponement, that contribute to UCCs' effectiveness. The article summarizes insights from recent studies to present the critical design considerations.*

Keywords: *urban consolidation centre, material supply, logistics process improvement, key performance indicators, material handling design.*

1. INTRODUCTION

Experts project substantial growth in the global logistics sector over the next years. This trend is driven by factors such as technological advancements based on Industry 4.0 technologies (Internet of Things, digital twin, cloud computing, big data solutions), increased globalization, and a rising demand for efficient supply chain management across various industries. In 2020, more than 4 billion people lived in cities, and experts forecast that 66% of the global population will live in cities by 2050 (see Fig. 1). Developing countries will experience the most significant urban development [1].

Experts expect the market to expand at a compound annual growth rate (CAGR) of 13.8% from 2023 to 2027, creating significant opportunities for businesses and stakeholders in the industry [2]. The growth of the global logistics market, based on technological advancements and the demand for more efficient supply chains, is leading to the expansion of UCCs, which enhance the efficiency of last-mile deliveries and help reduce environmental impacts, greenhouse gas emission in urban areas [3]. An UCC is a facility located outside a city centre where operators consolidate, sort, and prepare goods for more efficient last-mile delivery into the urban area. Typically, UCCs reduce the number of vehicles entering the city centres, improving traffic flow and decreasing environmental impacts by utilizing cleaner transportation options like electric vehicles, cargo bikes, or even river-based logistics [3].

Several examples of green urban logistics initiatives exist, and they are focusing on UCCs. In these systems, logistics hubs located outside city centres manage urban goods distribution, and operators transport the goods to downtown shops and private users using environmentally friendly methods. Paris has implemented UCCs on the outskirts of the city. Delivery trucks first bring goods to these hubs, and from there, operators transport the goods

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to shops in the city centre using electric vehicles or cargo bikes. The initiative helps reduce traffic congestion, air pollution, and carbon emissions [4, 5].

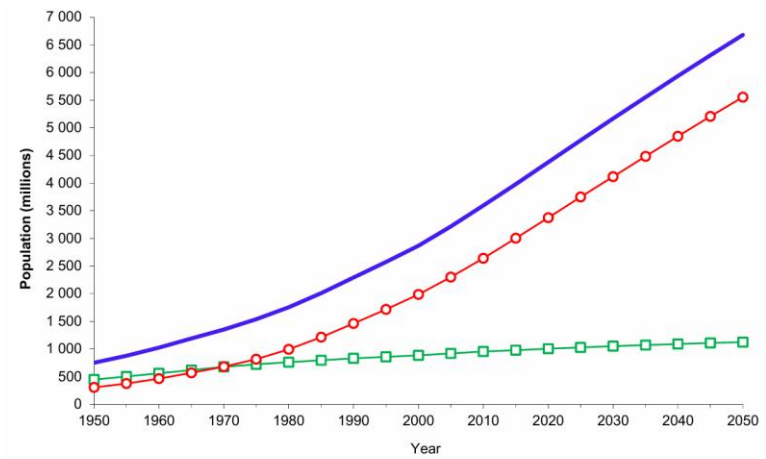

Figure 1. *Estimated and projected urban populations of the world [1]*

Amsterdam uses urban logistics hubs combined with electric boats and cargo bikes for downtown delivery. Goods arrive at a centralized hub outside the city, and operators use environmentally friendly modes of transport to distribute them. This system uses Amsterdam’s extensive canal network to reduce road traffic [6]. Logistics hubs outside London handle goods consolidation, and operators distribute them via low-emission vehicles or bicycles. Projects like the "Freight Consolidation Scheme" aim to minimize heavy goods vehicle trips in the city. Amazon and other companies also use similar setups in London to manage urban deliveries [7]. In Stockholm, construction projects use 19 million tonnes of excavated materials each year, while 16 million tonnes of construction waste are generated, with only a small portion being reused. To improve material reuse and improve efficiency, the Mass Consolidation Centre was established in 2018 at Frihamnen in Stockholm Royal Seaport (see Fig. 2) [8].

Figure 2. *Mass Consolidation Centre in Stockholm Royal Seaport [9]*

In 2002, Copenhagen implemented a zone access fee scheme based on vehicle properties and capacity utilization. The Citylogistik-kbh UCC, like other UCCs, struggles to maintain high throughput. Most goods arriving in the city centre come via the E20 highway, located south of Copenhagen, and the UCC is situated close to this highway. Copenhagen also uses micro hubs combined with cargo bikes and electric vans to ensure last-mile deliveries. Goods are first delivered to these hubs, strategically located outside the busiest parts of the city [9,10]. There are also other examples for UCCs (e.g. Utrecht, Barcelona, Vienna, Oslo, New York City, Hamburg, Milan, Zurich, Gothenburg or Tokyo); the large number of UCCs highlights their effectiveness, demonstrating their positive impact on urban logistics by optimizing delivery processes, reducing congestion, and minimizing environmental footprints. This impact is increasingly recognized in cities and industries worldwide, as UCCs are seen as a sustainable solution to enhance efficiency and reduce traffic-related issues in the case of downtown areas, shopping centres and other urban areas.

Within the frame of this article, the authors review the existing literature on the design and operation of UCCs. Based on the results of the literature review, the most important design models and methods related to the design and operation of UCCs are discussed.

2. Literature Review

UCCs are a growing focus in the field of sustainable urban freight transport, aiming to environmental and logistical challenges. This literature review summarizes key contributions from recent studies to outline the progress, challenges, and future directions of UCC research. Researchers conducted an extensive review of UCCs, identifying 114 schemes in 17 countries, primarily in the EU [11]. The study highlights the peak in UCC development between 2006 and 2010, emphasizing their significant role in reducing traffic and environmental impacts in urban areas. It also discusses the organizational, operational, and financial factors critical to the success of UCCs [12]. A research study discusses a UCC trial in central London that uses electric vehicles and cargo tricycles for urban freight delivery. The study demonstrates a 54% reduction in CO_2 emissions per parcel, highlighting the environmental benefits of UCCs. However, it also identifies logistics challenges, such as increased travel distance per parcel due to smaller vehicle capacities, underlining the importance of balancing efficiency and sustainability in freight operations [13].

Researchers published a study focusing on the exploration of potential demand for UCCs through a stated-preference study in Fano, Italy. Their findings indicate that factors such as parking distance, access permit costs, and service costs significantly influence the adoption of UCCs. The study also highlights the potential of regulations to increase UCC utilization, offering insights into designing policies to promote sustainable freight solutions [14]. A research group examined the feasibility of implementing a UCC in The Hague, using case studies from similar European cities. They identify financial and stakeholder collaboration challenges as major barriers to UCC success. This study emphasizes the need for municipal involvement in aligning costs and benefits, offering actionable recommendations for future UCC initiatives [15]. Barriers to be implemented a UCC in Oslo, emphasizing financial and stakeholder acceptability issues were discussed by a study [16]. The study discusses an implementation theory to propose strategies for overcoming these challenges, such as developing a robust business model. This novel approach provides a framework for policymakers and researchers to better understand and address obstacles in urban freight policy.

Researchers conducted a systematic literature review to categorize UCC research and identify gaps. They find that while UCCs address significant environmental and social challenges, financial viability and stakeholder management remain underexplored. The authors proposed a future research agenda focusing on measuring impacts, financial considerations, and stakeholder collaboration to enhance the practical implementation of UCCs [17]. A research group explored the dispatching problem at urban consolidation centres by presenting a Markov decision model and developing an approximate dynamic programming algorithm to handle large-scale instances. Their numerical experiments demonstrate the effectiveness of this algorithm, which consistently outperformed benchmark policies, particularly under flexible distribution conditions [18]. An article provided a comprehensive review of UCCs, analysing their potential to reduce vehicle traffic and improve supply chain efficiency through six case studies. The study identifies critical success factors, emphasizing the role of UCCs in achieving commercial and environmental benefits while highlighting the need for adaptable and well-planned implementation strategies [19]. Researchers identified seven critical factors for novel business models in city logistics involving UCCs, such as scalability, innovation, and IT utilization. Their study highlights the importance of dynamic adaptability and municipal involvement for UCC success, contrasting purely commercial and municipal initiatives [20]. In a research article, the localization of freight consolidation centres in Gothenburg and highlighted barriers such as congestion and inefficient transport systems were examined. Their findings highlight the necessity for policymakers to consider city-specific factors, given limited potential for success under current conditions [21]. A research group focused on construction logistics, revealing that construction consolidation centres (CCCs) could significantly reduce freight movements and pollutant emissions. Through eight months of data from four construction sites, they demonstrated the unique characteristics of construction logistics and called for greater attention to this segment from researchers and policymakers [22].

Researchers proposed a novel methodology for evaluating UCCs' carbon efficiency. Their study in Lucca, Italy, demonstrates potential CO_2 savings and highlights the financial viability of UCCs through external funding, suggesting the model's adaptability to other urban contexts [23]. The Bristol-Bath UCC was discussed, showcasing its positive impact on logistics efficiency and environmental impact. The study highlights significant benefits for retailers, such as improved staff productivity and reduced packaging waste, positioning UCCs as a valuable tool for sustainable urban logistics [24]. Researchers developed an analytical approach to estimating the cost-effectiveness of UCCs. Their framework revealed that UCCs could reduce time-related delivery costs, with cost attractiveness influenced by operational, locational, and service-area characteristics, demonstrated through a case study in Brussels [25]. A research group studied a consolidation centre in Southampton serving urban retail businesses. They evaluated operational scenarios and environmental impacts using a multistage analysis framework. Their findings emphasize the importance of operational planning and vehicle utilization optimization in enhancing the centre's effectiveness [26].

The literature review reveals that UCCs have shown promise in reducing traffic congestion and CO_2 emissions, particularly through innovative approaches like the use of electric vehicles and cargo tricycles. However, operational challenges such as increased travel distances per parcel and financial sustainability remain significant barriers. Studies highlight the critical importance of factors like scalability, stakeholder collaboration, and municipal involvement in ensuring the viability of UCCs. While demand for UCCs can be influenced by policy measures like parking regulations and access costs, the feasibility of implementation depends heavily on city-specific characteristics and targeted support. Research on UCC dispatching algorithms and cost-effectiveness frameworks has demonstrated efficiency gains, but financial and logistics constraints persist, underscoring the need for adaptable and well-planned solutions. Overall, UCCs have potential for sustainable urban logistics, but addressing challenges such as stakeholder alignment, business model development, optimal design and operation of logistics processes, and tailored urban policies is essential for their success.

Based on the above discussed short literature review, it can be concluded that the effective design and operation of UCCs is significantly influenced by proper structuring of logistics processes. Key planning tasks include the selection of optimal facility location, vehicle routing, scheduling, and load optimization to ensure key performance indicators including availability, flexibility, efficiency, transparency and sustainability. The article will therefore focus on addressing these essential logistical planning tasks in the context of UCCs. By analysing these aspects, it aims to contribute to the development of more effective and adaptable UCC solutions.

3. MATERIALS AND METHODS

In this chapter, the key design tasks related to the establishment and operation of UCCs are summarized, with a focus on how they significantly contribute to logistics efficiency and sustainability. These tasks include the planning of location and facility layout, which are crucial for ensuring optimal operations and reducing environmental impacts. Routing decisions are also emphasized, as they play an important role in minimizing travel distances and improving the overall efficiency of the supply chain. Furthermore, warehouse design is discussed, highlighting the importance of selecting appropriate storage systems and material handling equipment. The chapter also covers the integration of e-mobility and micromobility, which are important in reducing emissions and enhancing last-mile connectivity. Lastly, different operational strategies such as cross-docking, consignment, and postponement are explored, offering flexibility and cost-efficiency in UCC operations.

3.1. Facility Location

In the case of UCCs, several facility location problems must be addressed to ensure their effectiveness. These problems typically include the optimal site selection which focuses on the determination of the best location for the UCC within or near urban areas, balancing proximity to delivery points and accessibility for inbound logistics from suppliers. In this design task, it is important to focus on coverage and accessibility, which means that the UCC must be located within a reasonable distance to maximize the coverage of the urban area while minimizing transportation costs and time for both last-mile deliveries and supplier shipments. Infrastructure availability also plays an important role, because the suitability of potential available sites based on infrastructure requirements such as road connectivity, space for loading/unloading, and storage capacity must also be taken into consideration. As important aspects, minimization of environmental impact, stakeholder and economic factors are also to be taken into consideration. Existing urban logistics networks, public transportation systems, and policies such as low-emission zones or urban freight corridors can also influence the results of facility location problems. The key considerations in facility location for UCCs are shown in Fig. 3.

Figure 3. *Key considerations in facility location for UCCs (own edition)*

3.2. Routing

In the case of UCCs, several routing problems need to be addressed to ensure efficient and cost-effective operation. The solution of vehicle routing problems (VRPs) is a significant design task, because it covers the determination of the optimal routes for delivery vehicles that minimize travel time and costs, considering factors such as traffic, time windows for delivery, and vehicle capacity. Last-mile delivery routing is also important, because planning the most efficient routes from the UCC to the end customers can significantly influence the efficiency and sustainability. In cases where multiple UCCs are located in a region, determining how to best distribute goods between the UCCs and delivery vehicles to optimize overall network performance is a core optimization problem.

The importance of digitalization, application of Industry 4.0 technologies, and real-time optimization can be highlighted in the case of adaptive routing, because changing conditions (unexpected traffic, delays, or last-minute orders) are significant in urban environments. Environmental impact of routing is also important; the objective function of routing problems must cover not only fuel consumption minimization but also emission reduction. Optimizing routes for both the collection of goods from suppliers and the delivery to customers, ensuring efficient use of vehicles and time are also significant. These routing problems require advanced algorithms and real-time data to ensure the UCCs operate efficiently while minimizing costs, emissions, and other operational challenges. The key considerations in routing for UCCs are shown in Fig. 4.

Figure 4. *Key considerations in routing for UCCs*

In the case of routing, Cselényi and Illés suggested a planning process that includes nine phases [27], as shown in Fig. 5. This proposed approach was defined for conventional routing problems, but it is possible to adapt the main phases of this approach to be suitable for solving routing problems in the context of UCCs, as follows:

- Definition of system boundary: urban zones often have limited access, congestion, and environmental regulations.

- Definition of material flow tasks: focus on minimizing handling time while ensuring efficient consolidation to reduce vehicle trips and improve delivery efficiency.
- Definition of material flow matrix: understanding the flow of goods between suppliers, the OCC, and end delivery points, as well as the volumes and frequency of movement.
- Selection of loading units: Standardizing unit loads to ensure compatibility with vehicles and handling equipment. Use of modular and reusable units such as roll cages or small pallets suited for urban environments with size restrictions and sustainability goals.
- Selection of vehicles: Preference for smaller, electric, or low-emission vehicles to navigate narrow streets and comply with emission regulations.
- Design of loading and unloading locations: Optimizing the layout of docks and bays to minimize loading/unloading time and maximize throughput. Urban centers often have space constraints. Efficient designs must consider quick turnover, safety, and integration with pedestrian traffic.
- Routing: Incorporating real-time traffic data, delivery time windows, and environmental zones into the routing process.
- Calculation of the amount of required transportation resources (vehicles): Determining the optimal number and type of vehicles required to meet service level agreements. Account for fluctuating demand, seasonal peaks, and shared vehicle use among multiple service providers.
- Design of control system: Urban logistics benefit from advanced IT systems and IoT for dynamic routing, vehicle tracking, and real-time updates to improve efficiency and reliability.

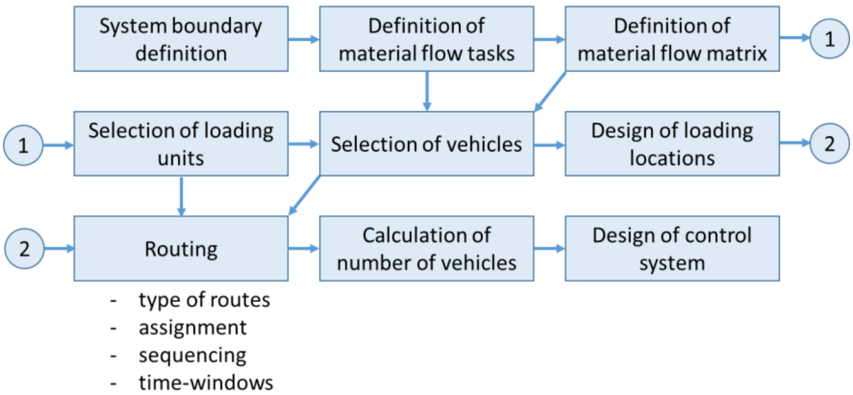

Figure 5. *Conventional planning process [27]*

3.3. Warehouse design

In the case of UCCs, several key warehouse design problems need to be addressed to optimize the efficiency and effectiveness of the facility. Space allocation is a key problem, because it is important to allocate space for different types of goods, storage, and materials handling operations in the UCC, ensuring efficient use of space while allowing for flexibility in operations. Designing the internal layout plays an important role to ensure smooth material and information flow (flow design), minimizing congestion and reducing handling times for incoming and outgoing goods. Selecting the most suitable storage systems (e.g., pallet racks, shelving, automated systems) based on the types of goods handled and the expected volume has also a significant impact on the efficient operation of UCC. The selection of a suitable storage system is related to choosing appropriate material handling equipment (e.g., forklifts, conveyors, automated guided vehicles), as ensuring efficient loading, unloading, and transport depends on the selected material handling equipment. IT solutions and tools like warehouse management systems (WMS), radio frequency identification (RFID), and automated sorting systems (ASS) are playing an important role in digitalized warehosuse processes to improve inventory control, tracking, and order fulfillment. Environmental design and sustainability are also unavoidable: sustainability objectives, such as energy-efficient lighting, use of renewable energy, and waste reduction systems are significant in a sustainable warehouse solution. The safety of workers and vehicles within the facility are also to be taken into consideration while planning warehouse for UCC. The key considerations in warehouse design for UCCs are shown in Fig. 6.

Figure 6. *Key considerations in warehouse design for UCCs*

3.4. E-mobility and micromobility

The significance of e-mobility and micromobility in the context of UCCs lies in their potential to address both environmental and operational challenges in urban freight systems. E-mobility, through electric vehicles, reduces CO_2 emissions and noise pollution, which are critical in urban areas where air quality and congestion are major concerns [28, 29]. Micromobility, which includes electric bikes and cargo tricycles, enables more flexible, cost-efficient, and sustainable last-mile delivery solutions, especially in dense urban environments [30]. These solutions help UCCs minimize their carbon footprint while ensuring efficient deliveries, even in areas with restricted access or traffic congestion. The integration of these transportation modes into UCCs allows for greater scalability and adaptability, enhancing overall supply chain efficiency and reducing dependency on conventional, polluting delivery vehicles. By leveraging e-mobility and micromobility, UCCs contribute to the broader goal of creating sustainable and smart cities.

3.5. Cross-docking, consignment and postponement

An UCC can operate as a cross-docking terminal, a consignment warehouse, or incorporate postponement strategies. As a cross-docking terminal, the UCC focuses on receiving goods, sorting them, and immediately redistributing them without storing them for long periods, which reduces inventory costs and speeds up the flow of goods to their final destinations. When functioning as a consignment warehouse, the UCC temporarily holds goods on behalf of retailers or other customers, allowing them to manage inventory levels more efficiently without having to maintain their own storage facilities. This can help optimize space usage and reduce supply chain costs for businesses. Additionally, the UCC offers the potential for postponement, which involves delaying the final configuration or packaging of products until they are closer to the end customer. For example, items may be re-packaged or customized to meet specific customer demands at the UCC before final delivery. This postponement strategy allows for greater flexibility, as products can be tailored based on real-time orders, reducing waste and improving responsiveness. These functions enable the UCC to support a more agile and cost-effective supply chain, addressing the varying needs of businesses and contributing to sustainable urban logistics solutions. The choice between these operational models depends on the specific needs of the supply chain and the urban environment in which the UCC is situated.

4. Results and Conclusions

The cooperation and the distributed resource management play important role in the improvement of efficiency. As previous research works discuss [31-34], the cooperation between smaller logistical service providers and logistical centres offers several advantages, including increased task volumes for profitable operations, reduced investment payback periods, and centralized transportation management, which supports supply chain coordination. These aspects lead to the appearance and improvement of UCCs. Based on these aspects, this article provides an overview of the essential design tasks involved in establishing UCCs, focusing on their significant role in enhancing logistics efficiency and sustainability. It begins by examining the importance of location and facility layout planning, which are critical for ensuring smooth operations and minimizing the environmental impact of urban logistics. The paper emphasizes the importance of routing decisions, which help reduce transportation distances and improve the overall effectiveness of the supply chain. In addition, the article discusses warehouse design, underscoring the need to select appropriate storage systems and material handling equipment that support operational efficiency. Another key aspect covered is the integration of e-mobility and micromobility solutions, which contribute to reducing carbon emissions and improving last-mile delivery. The article also discusses various operational strategies used in UCCs, such as cross-docking, consignment warehousing, and postponement, which provide flexibility and cost-saving opportunities. By adopting these strategies, UCCs can offer efficient solutions to urban freight challenges while minimizing resource consumption and emissions. Furthermore, the chapter explores the impact of these strategies on the sustainability goals of UCCs, highlighting their potential to reduce traffic congestion and improve air quality. The article concludes by suggesting that UCCs, when designed effectively, can significantly contribute to the development of sustainable urban logistics systems. Overall, the piece offers a comprehensive guide to the design and operational challenges of UCCs, providing insights into best practices and emerging trends. Our future research goal is to develop new methods and models that enhance the efficiency of designing and operating UCCs.

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