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The Design of a Future-Proof Hub for Last-mile Delivery with Light Electric Freight Vehicles

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This research focuses on designing a hub for last-mile delivery with light electric freight vehicles (LEFVs). A design methodology is proposed, combining logistics knowledge with theories from architecture and product design. The research answers the question: *How can the design of a last-mile logistics hub using LEFVs be flexible and responsive to future changes?* There is not a singular answer as to how last-mile hubs will be affected because future changes consist of anticipated developments and uncertainties. The higher the uncertainty, the more flexibility is required in the design. Modularity is a key factor in making the design flexible and responsive to future changes because it allows components to be easily interchanged, enabling the hub to adapt quickly. The modular building blocks of the hub are developed after a thorough analysis of the system and its context.

Last-mile ; Delivery ; Hub ; LEFV ; Futureproof ; Modular ; Flexible ; Responsive

1. Introduction

Most people will be no stranger to the concept of a delivery van driving into their street. But especially in urban areas, this familiar sight is prone to disappear with new environmental regulations concerning urban air quality and CO^2 emission reduction. Urban logistics are the culprit of these emissions, with *last-mile* logistics being the largest cause of pollution in urban areas [1]. Thus, alternative methods for *last-mile deliveries* are highly needed. Solutions in terms of electric vehicles and alternative freight transport are already on the market. Yet, the logistic system is not tailored to the use of these vehicles. Therefore, this paper proposes the design of a *logistic hub,* for *last-mile delivery*, with *light electric freight vehicles (LEFVs).* A *last-mile logistic hub* can function as a transfer point, where support vehicles (SVs) redistribute their freight to *LEFVs.* A *last-mile hub* could be involved in the sorting and distribution of freight, plus it could act as a service and recharging point for *LEFVs.*

2. Research Objectives

In this report, a hub signifies a physical space where an exchange and transfer of goods can take place. Hubs can be situated within an existing area, they can exist in public space, or they are specifically built for their purpose [2]. However, little research exists on how hubs can be developed as a product.

To distinguish the hub as a product from an architectural structure, the hub should be off-grid, mobile, and modular. This allows the product to be positioned and re-positioned without complex installation or much pre-processing of the destined area. Another aspect that makes this hub a product, rather than an architectural piece, is the aspect of modularity. The hub should be available in different modules which can be combined to form different configurations.

But creating a hub as a product is one thing. Making it a viable product is another. To make sure that the hub becomes a profitable product, the future-proofness of the hub should be taken into account. This should ensure continuous relevance to the market. As opposed to many architectural works where buildings' functionalities hardly outlive their physical lifespan [3].

This challenge can be summarized in the following research question:

How could the design of a last-mile delivery hub, using light freight vehicles, be flexible and responsive to future changes?

2.1. Value proposition

The goal of this research is to develop a methodology for the design of a hub for last-mile delivery with LEFVs in urban areas, that can be used and sold as a product. Various research has already been conducted in the field of smart-, urban-, and last-mile logistics. However, if such experiments even involve last-mile hubs at all, these last-mile hubs are often mere tools to an end. Compared to the extent to which logistics have been studied, little research has been done on the actual requirements for a last-mile hub. This paper will introduce a design methodology, which supports the identification of those requirements, and which focuses on generating futureproof hub designs. In section 4. Synthesis, the methodology is applied to a use-case of LEFV delivery with Fulpra LEFVs, in the timeframe of 2024-2050.

3. Methodology

The aim of the proposed methodology is to provide a supportive framework for instances interested in developing a futureproof hub. The framework is applicable to last-mile delivery hubs, although it may be applicable to hubs with other raisons d'être as well.

3.1 System Approach

The methodology relies on a system view of the hub because hubs are multi-component systems with many internal and external interfaces. By approaching this problem systematically the effects of design choices are immediately reflected by the entire system.

3.1.1 Use cases

The system approach was implemented in the analysis of the stakeholders. Tools such as use cases are a common practice in system engineering. Use cases are a method to think up different components involved in activities that different stakeholders perform in relation to the last-mile hub.

The use cases are used to generate a list of activities and tasks that will be performed within the hub. This list will be used to determine the functionality of the hub and the module-composition.

3.1.2 Activity Relationship diagram

The activities identified in the use cases could then be translated into product functionalities. To uncover potential groupings of functionalities, an activity relationship chart can be used (ARC). The ARC is a chart that lists the different components, the basis of their relationship, and the intensity of the relationship.

After identifying the different tasks and activities within the hub, the most important or groupings of activities are put into an ARC. In this diagram the identified functionalities are plotted against one another. The chart results in a list of crucial proximities or distances. In the design of the hub, these findings are used to define the modalities of a hub. Modality grouping is closely related to making a floorplan, with the goal of minimizing the travelled distances of employees and goods.

3.1.3 Nine-window diagram

The nine-window diagram uses the current and past status of system elements to reason about potential future status of the system. This provides insight on the potential future sate of the world. The nine-window diagram is a method used in system engineering, which stimulates the user to reason about the past, current and future states of the system in different layers of depth.

The idea of the nine-window diagram will be combined with the theory of shearing layers and a future vision. Within the nine-window diagram only 3 layers of depth are specified: the context, product-level, and sub-component level. The theory of shearing layers extends these levels, going more in depth in an architecture-specific manner.

3.1.4 Shearing layers

Back in 1994, Brand introduced the concept of shearing layers in the built environment. This concept rejects the concept of a building and reduces it to a composition of layers. Within these layers a distinction can be made as to how quickly each layer could and should change for the building to be adaptable. In general, the inner layers should be quicker to adapt, whereas outer layers can be more inert.

The theory of shearing layers will be integrated with the nine-window diagram to go more in detail of the different product levels of hubs. The effects of trends and developments are projected onto each layer, to see the differences in effect and the differences in required response.

3.2 Future vision

In existing methodologies two main categories of futureproofing can be distinguished. Methods either focus on sketching a future vision and tailoring the product to the envisioned world's requirements. Or the design responsive strategies to foreseen and unforeseen events. This methodology combines a future sketching approach with a backcasting methodology.

3.2.1 Vision in Product Design

The Vision in Product Design (ViP) is a design methodology by Paul Hekkert and Matthijs van Dijk [4]. Within ViP the future context is defined by developments, trends, states and principles. After defining the future, a raison d'être for the product in this future context is established. This raison d'être specifies the role of the product in the future context. It describes the envisioned interaction that people will have with the product or service in the future.

From the ViP method, the idea of analysing the world in terms of trends, developments, states , and principles is used. These different factors concerning the world are then clustered into themes and relations. This approach will be used to constitute themes of the future context. Instead of defining one main raison d'être, the envisioned human-product relationship is stated per cluster and will be used to indicate certain future contexts.

3.2.2 Backcasting

Backcasting is a technique, originating in the 1970s, which focusses on defining an ideal future vision. Then, by backcasting from this scenario, the required steps to get to this state are uncovered. Ayfandopoulou et al. (2018) describe the ability to sketch a future vision in terms of probability, possibility, and preference. Probability bases its perspective of the future on trends and historical records. Possibility takes developments and restrictions into account. Within the preference a personal note can be attributed as to how the designer would like the future to look like.

The backcasting scenario is used after the future vision is projected onto the current system. By combining the future context with value stream mapping (section 3.3.1) the wastes are identified and alike backcasting, the required steps to solve those wastes can be identified.

3.3 Uncertainty Mapping

A primary requirement of a design methodology for a futureproof product is that it should be responsive. Because, although trends can indicate what to expect, unexpected events may always happen. Still, if a product were to be responsive to every potential future, it may become too universal and therefore lose its identity. Therefore, crucial uncertainties should be identified. The product should be tuned to adapt to these future uncertainties.

3.3.1 Value Stream Mapping

Value Stream Mapping (VSM) is a method used in Lean Management to identify value and waste in a process. Within Lean there is the notion of the 8 Muda, also known as 8 wastes. The 8 wastes concern inefficiencies in terms of Time, Inventory, Motion, Waiting, Overprocessing, Overproduction, Defects, and Skills. VSM is a visualization tool which can support the analysis [5]. By identifying "wastes" in the current system and potential wastes in the future state of the system, one could preliminarily identify required adaptations [6].

The ideal future state can be formulated by integrating the results from the future vision. Through VSM, potential wastes can be identified within the envisioned hub, also taking the identified uncertainties into account. The wastes can be solved through backcasting, TRIZ, and by problem solving with creativity techniques.

3.3.2 Sustainable Urban Logistics Planning

The Sustainable Urban Logistics Planning (SULP) cycle is a systematic approach for policymakers to respond to uncertainties. Elements of SULP can be applied to design queries as well. The SULP framework consists of 5 steps. Step 1 and 2 of SULP concern analysing the current system and identifying the challenges and complexities through forecasting, exploration, and informal information gathering. Step 3 specifies which adaptions should be made and the steps in which they should be executed. Step 4 identifies whether something is a threat or an opportunity, through which the robustness of policy measures can be increased. Step 5, responsiveness, is promoted by having corrective actions ready, and being prepared to reassess the policy goals and measures [7], [8].

The SULP cycle is more of a general framework in which inspiration is drawn about the order of steps. Steps 1 and 2 are filled in by the system approach, future vision creation, and uncertainty mapping. Step 3 and partly Step 5 encompass VSM and backcasting. Steps 4 and 5 define the iterative element of the methodology where solutions are (partly) evaluated and adaptations can be made.

3.3.3 Failure Mode and Effect Analysis

A failure mode and effect analysis (FMEA) lists all potential failure modes of a product or service. It specifies the cause, responsibility, severity, occurrence, and detection chance per failure mode. Using the risk priority number (RPN) the most crucial failure modes are identified [9].

The FMEA is one of the methodologies that can be used in the iterative aspect of the methodology (step 4 and 5 of the SULP cycle) to assess which elements are still high-risk and require additional work. This methodology often uses a partial FMEA to further explore uncertainties and novel solutions. The FMEA is also used in the evaluation segment of the methodology. Where the identified risks are associated with the rating of concepts.

3.4 Responding

After identifying uncertainties, the goal is to minimize the impact of uncertainties. This is done by being readily responsive to the identified uncertainties..

3.4.1 TRIZ

Often associated with VSM in Lean Management, Teoriya Resheniya Izobretatelskikh Zadach (TRIZ) can be used to solve wastes. TRIZ is a toolkit developed in 1946 by Genrich Altshuller. It holds a large set of generalized solutions. Stripped down problems all yield several solutions, which can be translated to the actual problem domain [10].

TRIZ will be applied as one of the strategies to solve uncertainties and wastes as identified in Uncertainty Mapping. TRIZ will be completed with strategies that stimulate creative thinking, for problems which cannot be solved with TRIZ.

3.4.2 Creativity strategies

Within design related fields, it is common practice to use methods to stimulate creativity. These activities can range from simple brainwriting session, to abstract meditation-like practices.

Creativity strategies will be applied where TRIZ is not sufficient or where additional abstraction of the waste or uncertainty is required to fit into the TRIZ format.

3.5 Validation

Throughout the design process and per design iteration cycle, choices need to be made with respect to the optimal concept. This is often done reflecting back on the requirements. Tools such as a Pugh Matrix employ the principle of weighted scoring to make a decision. These weights can be attributed based on distinct factors. Most often, user validation is taken as a weight. But other scales, such as sustainability or costs could be used as weights as well. Dependent on the goal of the product the scale may vary.

3.6 Verification

Different methods can be used to verify if the eventual product meets the product requirements and standards. A verification is often a type of test based on the requirements. Depending on the requirements the exact manner and type of test may vary. Therefore, there is no fixed verification method associated with this methodology other than that the requirements should be verified.

3.7 Methodology Summary

The methodology is constructed by integrating multiple existing methodologies into one framework. The methodologies come from different fields of expertise. The methodology will include elements of future-vision methods. These elements will construct a future context and identify the uncertainties within those contexts. Strategies to construct solutions to deal with those uncertainties are included. Validation strategies are discussed, but verification strategies are not included in the scope of the methodology.

4. Synthesis

The key stakeholders associated with a last-mile hub can be grouped based on their influence and interest. Government bodies, such as municipalities and city councils, hold significant power as they can approve or restrict the hub's operations However, they are not likely to invest in the hub as it is outside their financial capabilities. Residents, cleaning staff, and freight drivers are stakeholders with less power, but their needs should be considered because their tasks in relation to the hub are crucial to its functionality. Parcel senders and receivers also have varying levels of interest—senders can choose to use the hub, while receivers have less control over the logistics choice. Maintenance, installation, and repair services have a higher level of interaction with the hub, giving them more influence. The most actively involved stakeholders are logistics providers and hub employees, as they rely directly on the hub's performance for their operations.

Associated with these stakeholders, different tasks and responsibilities are identified. These identifications could be grouped and translated to required hub functionalities as displayed in Figure 1. These functionalities can be explored further through a proximity mapping; the Activity Relationship Chart (ARC). This mapping is portrayed in Figure 1, where the functionalities are listed and indexed on the left side. The relationships between the functionalities are described by the importance of the relationship and the flow-type of the relationship.

From this ARC, three modules: COMUS, LOS, and PACE arrived. COMUS stands for comfort, utility, sanitation. The LOS modality stands for Loading and Sorting. This modality will experience a high throughput of goods. PACE marks Parking, Charging, and Energy. Due to safety precautions PACE should be situated as much outdoor as possible. The high value content of PACE demands the modality to have a high degree of security.

Then a future vision is established inspired by the method described in ViP. Key themes emerged, including the pressure to regain control in a fast-paced, multitasking society. Also, breaking with traditional work, living, and societal aspects is identified. Environmental threats drive a demand for green products, generating a great acceptance for sustainable products. Lastly, the digital age has increased expectations for speed and a constant influx of information.

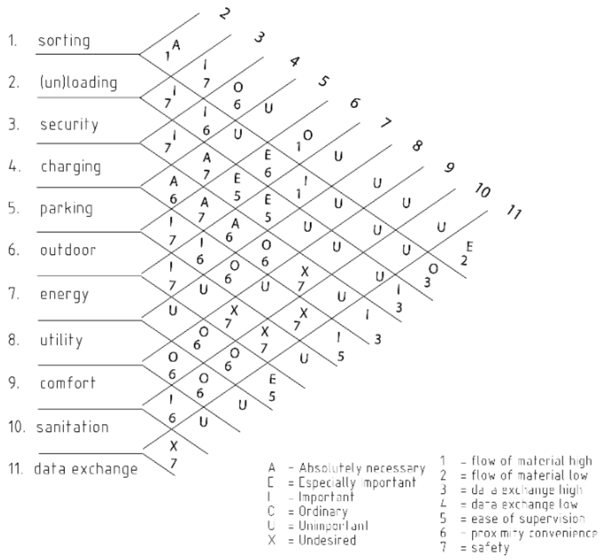

Figure 1.; The ARC diagram, on the left-hand side the identified functionalities of the hub. Mapped out against one another based on their relationship and flow type.

Applying this future vision to the different modules, it shows that COMUS is seen as the least uncertain modality due to its embodiment within the last-mile hub. This makes COMUS less susceptible to environmental changes. The key uncertainty lies in the materials and styling used in the skin layer of COMUS, which could become outdated. The "stuff" level also faces uncertainty due to trends or regulations, while the structure and service layers are expected to remain stable. Changes in the space plan might occur due to shifts in utilities or delivery vehicles.

In contrast, LOS faces greater uncertainty, particularly in the site, skin, and structure layers due to external factors like climate change, municipal regulations, and aesthetic changes. While core activities such as unloading remain constant. For PACE, uncertainties revolve around parking, charging, and energy management, which impact the structure and space plan. As PACE interfaces directly with delivery vehicles, evolving vehicle sizes and energy storage needs demand changes within PACE.

The methodology yields flexible and modular design as a solution to these uncertainties. To be flexible and responsive, adaptations and changes to the hub should be minimally invasive. This is obtained by using standardized components with non-permanent fixtures. Another factor which supports the flexibility and responsiveness of design is modularity.

Throughout the use of the methodology, the concept design is evaluated using several approaches. The first design cycle uses a Pugh matrix to assess the design based on stakeholder preferences. Given the multi-faceted nature of the hub, conflicting interests were addressed by weighing input from various users and stakeholders. Then, certain evaluations based on ergonomics and health and safety are performed. Near the final stages of conceptualization, tools like SolidWorks were employed to test the feasibility of specific elements.

6. Discussion

The methodology aims to provide an objective foundation for the design of a last-mile delivery hub. By combining various methods, the methodology offers a comprehensive view of the required features and limitations of a last-mile hub. The methodology yielded a strong emphasis on flexible and modular design. Application to multiple use cases should clarify if this emphasis can be justified, or if the methodology is promoting a bias.

Bias may be introduced because not all integrated methods were equally impactful. For instance, the *Sustainable Urban Logistics Plan (SULP)* helped structure the methodology but did not contribute a unique factor. The ViP methodology on the contrary was crucial in shaping the future context. Another influential method was Brand's shearing layers, which helped the segmentation of the hub. By replacing this domain-specific theory, the methodology may become applicable for use in other industries as well.

The methodology is largely futureproof itself, as long as the input remains relevant. Though adjustments to the methodology may be required if new insights into the integrated methods arise.

7. Conclusion

Answering the main research question: *How could the design of a last-mile logistics hub, using light freight vehicles, be flexible and responsive to future changes?*

By looking at the design quest from a system view, the complex product can be segmented into different modules. By making these modules independent, the product becomes flexible, resilient, and responsive. Modular design can be a supportive tool in the development of a last-mile logistics hub, flexible and responsive to future changes.

The modules should be constructed after a thorough analysis of the system and its context. This analysis could be supported by different methods derived from different fields of expertise. Within this research, a methodology is proposed in which various methods are combined, focussed on highlighting and developing different aspects of a last-mile hub. This methodology may support the development of a flexible and responsive last-mile delivery hub.

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