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Burggraaf, Diego; Jovanova, Jovana

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Design of a multi-functional vehicle which supports passenger and cargo transport

Diego Burggraaf
Department of Maritime and Transport Technology
Delft University of Technology
Delft, The Netherlands
dburggraaf@student.tudelft.nl

Jovana Jovanova
Department of Maritime and Transport Technology
Delft University of Technology
Delft, The Netherlands
j.jovanova@tudelft.nl

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***Abstract*—Online shops are responsible for a significant increase in the total volume of parcels which have to be transported. Due to the increase in volume there are more vehicles required to meet this enormous demand. This has a negative impact on the traffic flow on the infrastructure. A possible solution can be found in ride-sharing, as sharing resources paves the way to more sustainable designs. Public transport often operates with occupancy rates below the maximum, and a way to optimize it to combine it with parcel transport. A multi-functional vehicle which combines public and cargo transport in variable ratios could lower the impact of parcel vehicles on the traffic flow. The designing steps for a multi-functional vehicle are presented which lead to a more detailed case design. This case zooms in on small public transport vehicles which are often active between small towns. The multi-functional case design consists of an innovative solution based on reconfigurable chairs which enables a more efficient use of vehicle space. Multiple options to implement the multi-functional vehicles in the transport system are also discussed.**

***Index Terms*—Small public transport, Cargo transport, Parcel transport, Multi-functional vehicle, Ride-sharing**

I. Introduction

The well-known problems of traffic and congestion in urban areas are the main driver of the community working in Intelligent Transport Systems (ITS) to innovate new designs and services that combine different modes of transport. ITS focusses on improvement of safety, mobility, productivity and lower environmental impact. Advanced technologies support the design of new solutions and introduce more flexible, modular, sustainable and autonomous vehicles. However vehicle occupancy is still an open challenge, as not all vehicles are occupied at all times but they are still part of the traffic network contributing to the congestion. One way to address this problem is to combine passenger and parcel transport in reconfigurable manner that can optimally serve the demand, thus reduce the number of vehicles. The public and parcel transport sector are two big participants of the infrastructure. Public transport is responsible for a significant portion of the urban traffic flow, however the occupancy rate of public transport is not always optimal. The second participant is the parcel transport sector. The number of parcel deliveries has grown tremendously in the past decade and is expected to reach 200 billion globally by 2025 [1]. Due to this growth the parcel transport sector requires more and more transport volume to meet the demand, whereas the public transport sector often has occupancy rates below the maximum. The increase in vehicles puts a lot of pressure on the urban infrastructure and it is becoming more challenging to support the amount of cargo demand in cities [2].

If the parcel sector could utilize the redundant space from the public transport sector there are in total less vehicles required. Ride-sharing could be a promising solution to the increasing urban traffic [3]. This can be achieved by a vehicle that is able to adapt to the daily varying demand for both types of transport. One of the options is to design a multi-functional vehicle which supports both types of transport. Similar ideas have been explored by international companies like the Renault-Group [4] and Mercedes-Benz [5]. Vehicle which consists of multiple compartments that can be used for human as well as cargo transport is explored in [6]. However these concepts replace compartments or even the whole body of the vehicle, whereas in this research a multi-functional interior will be explored. Modular and adaptive designs can be further introduced to explore more innovative solutions.

II. Design Methodology

To derive design solutions for multi-functional vehicle, a design methodology presented and discussed in [7] was adopted. This method consists of the following three main stages: analysis, synthesis and evaluation, shown in Fig. 1.

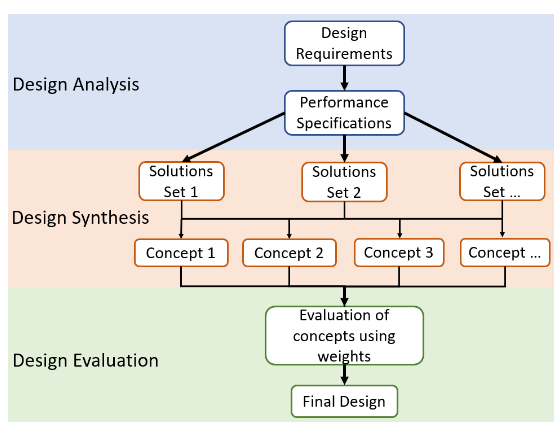

Fig. 1. A flowchart of the process of the design methodology

TABLE I
DESIGN REQUIREMENTS

R1	Variable public transport space
R2	Variable parcel transport space
R3	Keeping the handling times as low as possible
R4	Ensuring safety and security
R5	Maintaining comfort for the passengers
R6	Economically feasible

TABLE II
PERFORMANCE SPECIFICATIONS

S1	Transforming public transport space to parcel transport space
S2	Creating a storage system for parcels
S3	Separating the two types of transport

A. Design Analysis

When designing a multi-functional vehicle there are several aspects which need to be taken into account. Probably the most important requirement is that the vehicle has to support cargo transport as well as public transport in variable proportions. Secondly switching between both types of transport should cost as less effort as possible to keep the handling times low. The cargo space also requires a storage system to enable practical storing of the packages in the vehicle. Safety and security for both sides is also a relevant requirement; passengers should not be harmed by moving parcels whereas the parcel should not be damaged or even stolen by passengers. Other requirements which are less relevant, but still important are to the main course of this project are the level of passenger comfort and economic feasibility. Of course this new concept should be economically feasible, but that is not the focus of this research. All the requirements are summarized in Table I.

The performance specifications are a result of the listed design requirements. These specifications describe the tasks the design must fulfil. The performance specifications are listed in Table II.

B. Design Synthesis

In this stage of the design several conceptual solutions are derived for each design specification stated previously. The solutions are presented in Table III and for each concept a drawing is given in Fig. 2. This way of presenting the solutions was chosen to keep the main idea of the solution evident. In total four conceptual designs are presented based on different sets of solutions.

Concept 1
The first concept enables the addition of a cargo space without having to remove the chairs from the van. Folding the chair can be done as with every standard car seat and this opens up more space. A panel from the side wall of the van can rotated downwards so that a floor for the cargo space is created. The back wall of the cargo space will be created by a rolling shutter. This system can often be found applied to windows. This cargo space can be expanded by folding the next set of chairs, floor panels and rolling shutter. The advantage of this concept is the fact that it uses mostly already existing products.
Concept 2
The second concept replaces passenger space with cargo space by removing the seats completely from the rails. The back wall of the cargo space is formed by doors which can be rotated from parallel to perpendicular to the wall. These doors are removed when they are not in use. The cargo space can be expanded by doing the same operation for the next set of chairs. Also, for this part there are doors to create the next back wall for the cargo space. The notable difference from concept 1 is that this one creates more space. The use of doors in this concept instead of a rolling shutter might be more appealing to the passengers, because these can be partially transparent to give a more spacious feeling. However this concept requires more effort to transform the vehicle from one mode to another.
Concept 3
The third concept is the easiest to implement as has a fixed cargo space above the passengers seats. However normally the vans are designed is such a way that comfort is ensured, but this idea trades some comfort in for cargo space. This concept does relatively provide the least amount of cargo space in comparison to the other concepts. The fixed cargo space ensures a low handling time to use the cargo space. The only task needed to be performed is the loading of the packages into the lockers. Due to the simple system the totals costs of this concept are low.
Concept 4
This concept is quite different to the concepts presented previously. The positioning of the chairs in the van is different, instead of facing the front of the vehicle they will face each other. This is not the only change associated with the seat, a new type of chair mechanism is introduced. A part of the vehicle can be transformed into parcel space by pulling up the chair along a linear guide which is mounted to the wall of the van. This enables a more efficient way to use the space without having to remove the chairs completely. Arms can be rotated downwards to create supports for optional

TABLE III
SOLUTIONS TO THE DESIGN SPECIFICATIONS

Solution	Transforming public transport space to parcel transport space	Creating a storage system for parcels	Separating the two types of transport
1	Keep the chairs in position	Lockers	Doors
2	Folding chairs	Shelves	Rolling shutter
3	Removing chairs		Lockers
4	New type of chair		

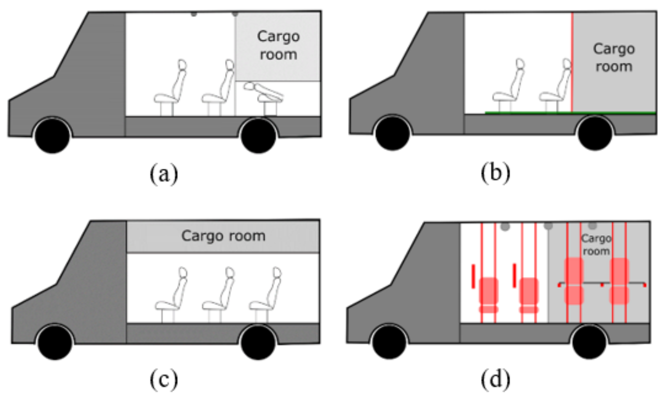

Fig. 2. Sketches of (a) Concept 1, (b) Concept 2, (c) Concept 3 and (d) Concept 4

shelves. These shelves will be stored in the floor when they are not being used. The cargo room can be separated from the passengers by using the same idea as in concept 1, a rolling shutter. This system keeps the handling time low while also creating relatively more volume for transporting cargo.

C. Design Evaluation

Choosing a concept for the case design is done by using the Weighted Objectives Method [7]. This method evaluates a limited number of concepts using a set of weighted criteria. The criteria are: handling, costs, space, comfort and security. Each criterion will be assigned a weight (1, 2 or 3) according to the importance it has to the design. The criteria will be given attribute values from 1 to 5 and this score will be multiplied by the weight of the criterion.

- **Handling** is important because the operator of the vehicle has to transform the space as fast as possible. This will enable the operator to accept orders on a shorter notice. For this reason the aspect will be given a weight of 2.
- **Cost** is nearly always an important factor. For this design an estimated cost will be considered for the parts the design requires. Because it is not the main focus of the design the price will be given a weight of 1.
- **Space** is the most important aspect of the design, because it is optimal to create as much room for the cargo as possible. Due to this importance the aspect space will be given a weight of 3.
- **Comfort** is also an aspect to consider. The passengers must not encounter too much discomfort as a result of the new design. However, this is not the most important aspect of the design, so it will be given a weight of 1.
- **Security** is the fifth aspect that will be evaluated for each concept. Security in this instance is the protection of cargo. This comes down to the separation of cargo from the passengers, because the exterior security mechanism is already designed by the original vehicle designer. Security will carry a weight of 2 because it is always important to ensure the protection of the cargo.

TABLE IV
THE RESULTS OF THE WEIGHTED OBJECTIVES METHOD

Concept	1	2	3	4
Handling (2)	4	2	5	3
Costs (1)	3	2	4	3
Space (3)	2	4	1	4
Comfort (1)	4	3	1	3
Security (2)	3	4	4	3
Total score	27	29	26	30

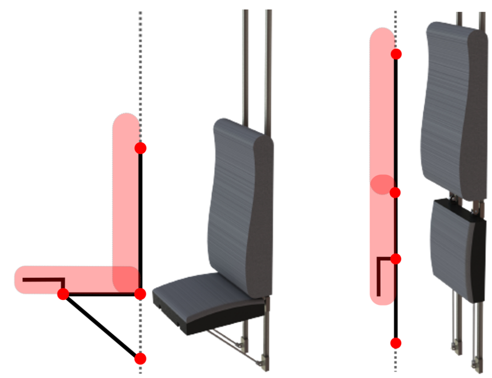

Fig. 3. The chair in the down position (left) and in the lifted position (right)

When the concepts are evaluated it results in Table IV. It can be seen that concept four has the best total score, so this is the concept that will be used in the multi-purpose vehicle case design. This research is currently done for small public transport vehicles, like the Mercedes Sprinter for example. This does not exclude that these concepts can be slightly modified and be used in other types of vehicles like city busses.

III. MULTI-PURPOSE VEHICLE CASE DESIGN

The concept 4 is used for the multi-purpose vehicle case design. The case design is presented in a 3D CAD model that only includes the loading bay of the vehicle due to its relevance. The different components of the design are discussed followed by the model. The dimensions used are from a Mercedes-Benz Sprinter, this vehicle is commonly used for small public transport as well as for cargo deliveries in the Netherlands. The dimensions are extracted from a technical data sheet published by the manufacturer. Small public transport has a maximum capacity of eight seats, so this capacity is also used for this design.
The idea is to design a chair that would not need to be removed from the vehicle, but which would also not take up as much space as the standard bus chair. A chair which can be pulled up when it is not needed is the design solution. The basic working principle is sketched in Fig. 3.
The chair will have three connections to the vertical guide on either side of the chair, so in total it is attached in 6 places. The lower seat of the chair will be supported by two steel tubes. The lower part of the chair is designed using dimensions given by existing ergonomic recommendations. This component is

not designed to the last detail, because it will be an existing seat with modifications made to it. These modifications include the hinge connection to the support rod, the linear guide and the upper part of the chair.
The upper part of the chair is designed in the same manner as the seat of the chair. The backrest received modifications to comply with the connections to the seat, the linear guide and the linear piston. At the bottom there are two flanges which can be connected to the seat as well as to the linear guide block. Two other guide blocks are mounted to the back of the chair as can be seen in the figure. These components combined enable the backrest to move along the linear guide. A cylindrical space is cut out from the upper face of the backrest to make space for an actuator.
An actuator is used to change the position of the chair automatically. This piston can be activated by a control panel located in the back of the van. The piston is able to lift the full weight of the chair up if the room has to be transformed into cargo space.
When passenger space is transformed into cargo space shelves can be put into place. This system comprises two components, namely the shelves and the arms that support these. The shelves are made of high-density polyethylene. This material is also used in reusable and foldable crates. The dimensions of the shelf support two different layouts of the cargo space. If only one or two layers are used the driver does not have to walk through the van so the full width of the van can be filled with shelves. If a bigger portion of the van is transformed into cargo space the driver is not able to reach the cargo further inside the van, so a path in the middle is required. The shelves can be easily placed on the support arms using the corner cylinders on the bottom of the shelf. On the other side of the shelf are holes which can be used to stack the shelves on top of each other. The shelves are placed on support arms when the room is transformed into parcel space. The support arms can be extended to create a shelf which spans the complete width of the vehicle. The arms are raised when the space is used for public transport. Steel is foreseen to produce these arms; this material supports the weight of cargo placed on the shelves.
If all components are put into one assembly the complete picture of the design can be seen. In Fig. 4 the vehicle can be seen when it is only used for public transport (*all renders are made in SolidWorks*). The renders do not include windows yet. This aesthetic feature can still be added in multiple ways as long as they don't block the chair system.

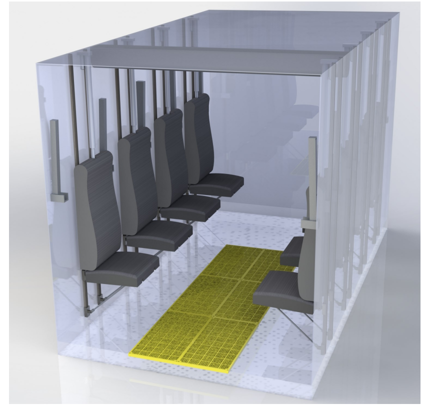

Fig. 4. The vehicle in full passenger mode

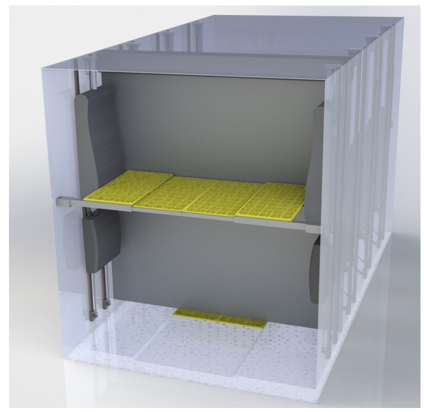

Fig. 5. The vehicle in 25% cargo and 75% passenger mode

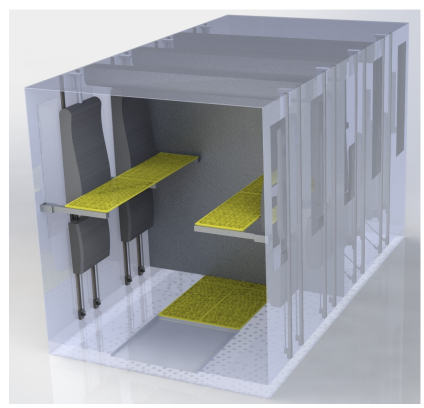

Fig. 6. The vehicle in 50% cargo and 50% passenger mode

The vehicle is able to change its capacity in a variable manner. The fractions of passenger and cargo space can be different depending on the lay out of the van. The vehicle will have a total of five different modes for a vehicle with eight seats. These modes work with pairs of opposite chairs. When the vehicle is in full passenger mode, all seats are down and there is room for eight passengers. The next mode is 75% for passengers and 25% for cargo, this is achieved by pulling up the pair of chairs starting from the back of the van. The first rolling shutter is then activated to separate both rooms. This mode an be seen in Fig. 5. The other three modes (50%-50%, 25%-75%, 0%-100%) can be achieved by each time pulling up the next pair of chairs and the next rolling shutter. Eventually every chair is pulled upwards and the whole van can be used to transport cargo. Fig. 6 presents the vehicle in the 50%-50% mode. The modes here are designed withing an existing van design. More innovative designs are possible if energy efficiency is explored based on shape and aerodynamics.

The vehicle has an integrated system which controls the chairs and the rolling shutters. This system has the following working principle; the linear piston which controls the position of the chair and the rolling shutter are activated by a central control unit that could receive information from a driver or in a more advanced version, from real-time demand. The control scheme can be seen in Fig. 7, including where the pistons and shutters are located. The active components for each mode are shown in the right side of the figure. Once the decision for a mode has been made, the control system will adjust the vehicle autonomously. The components are activated according to the selected mode. For example, if mode 2 (75% passengers-25% cargo) is chosen the last two chairs in the vehicle will be pulled up, so piston 1 and 2 are activated which belong to these chairs, the most rear rolling shutter, shutter 1 is also activated. Certain concepts like shape morphing [8-10] can be beneficial for shape change based on the occupied space in the cabin. This can increase the sustainability of this concept.

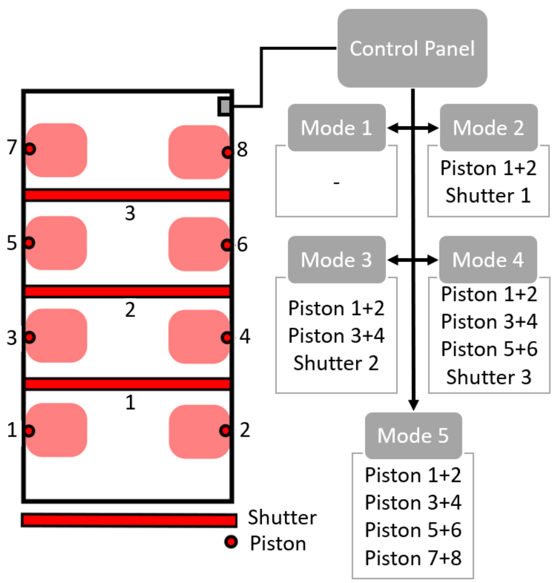

Fig. 7. The vehicle in full passenger mode

IV. Vehicle implementation

Several ideas for implementing this vehicle in a transport network are discussed in this section to show the potential for implementation and the benefits of multi-functional vehicle. These implementations could require new business models to efficiently integrate them in society. Each implementation uses the current small public transport as a starting point and adds changes to this system. The first three implementation methods: Central Collecting Station;Parcel Locker Station; and Home Deliveries, are about replacing a standard small public transport van with this concept vehicle. The last idea, App based system, follows a different approach based on ride-sharing services that disrupted the transport systems world wide, and opened the way for different business models.

Central Collecting Station

The first way of implementing this vehicle is to choose a central location in the town where the vehicle stops for a certain time period. Parcel recipients will receive a schedule with the times and locations of the vehicle. The current small transport vehicle only has a few stops in each village, so this method won't affect the driving times significantly. Recipients might receive a live location via an app or website to see if the vehicle has not experienced any delay or might be there earlier than expected. This implementation idea will increase the effort of ordering items online so the level of comfort will decrease slightly. The people will also have to be able to get to the stop when the vehicle arrives there, this might be a problem. But on the other hand, they would have to be at home when the parcel would be delivered at home. In Fig. 8 the central collecting station implementation is depicted.

Parcel Locker Station

Parcel lockers are an already existing concept that is being used in densely populated areas. A courier fills lockers with parcels and people can retrieve their package by using a code they have received to open the locker which contains their parcel. Parcel lockers could also be a practical solution for this concept. By placing parcel lockers at the location where the vehicle will stop the driver will fill the lockers before driving to his next destination. This method does not affect the driving times significantly and will enable people to choose their own moment of retrieval.This could be a solution for people who are working during the day and are not able to order packages because of this. Fig. 9 gives a schematic example how this implementation would work.

Home Deliveries

Home deliveries will also still be an option, but this will significantly increase the tasks a driver has to perform. Depending on the driving schedule it can lead to longer travelling times depending if there are still passengers in the van during the deliveries. The level of comfort will remain the same as for the current method of parcel home deliveries. However, the total time is weighed more heavily than the level of comfort. In Fig. 10 the increase in driving distance can be clearly seen.

App based system

The vehicle with a multi-functional interior also has potential to be deployed in the private sector. Firstly, ride sharing apps like Uber and Lyft, even though relatively new branch of a passenger transport, have gained increased interest. Expanding the same concept with passengers and delivery might increase their popularity. People can order a vehicle to drive them from one point to another, or ask for a parcel to be picked up and delivered by making a reservation trough an app. Secondly, companies which deliver groceries and medicines to people at home, could explore the option of utilizing the space in public transport vehicles. These vehicles could combine the best of both worlds by transporting groceries, medicines and people at the same time. This idea could be made possible with

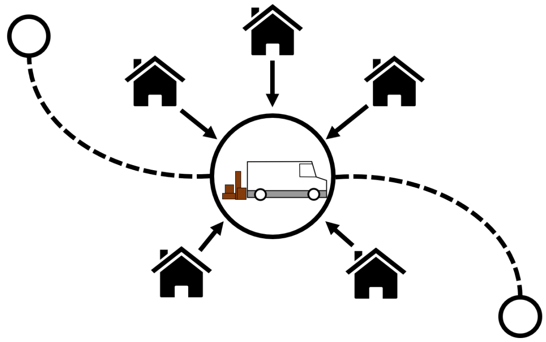

Fig. 8. Central collecting station

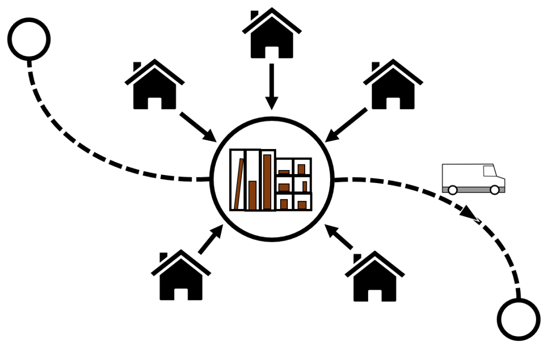

Fig. 9. Parcel locker station

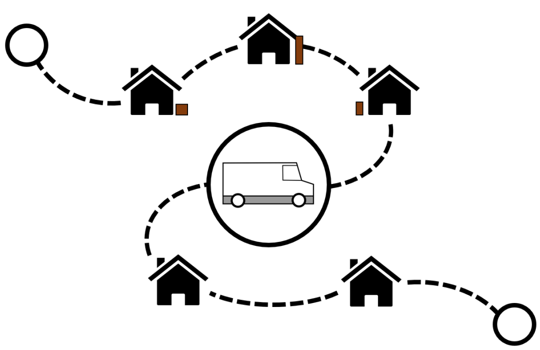

Fig. 10. Home deliveries

a smart planning system which efficiently combines routes for both types of transport. There are current research efforts in modelling the demand and understanding the benefits of multi-functional vehicles that support passengers and cargo transport simultaneously. The results are very promising which can lead to more efficient transport systems. Another trend is autonomous vehicles for passengers transport or delivery services especially in small distances. The multi-functional vehicle concept can be fully automated and can configure itself based on the demand. Looking at the future of autonomous vehicles, these type of multi-functional vehicles of different sizes will definitely find their way in the development.

V. CONCLUSIONS & FUTURE RESEARCH

This paper presented a novel design for multi-functional vehicles that can support passenger and parcel transport simultaneously in reconfigurable manner. Three stages were used to create and choose a promising concept: analysis, synthesis and evaluation. A commonly used vehicle for both, passenger transport and parcel deliveries, was used as a starting point for the design. The interior of the vehicle was modified by developing a pull-up chair and a shelf system showing that it is possible to design a vehicle which is able to transport passengers and parcels in variable proportions. The vehicle could also help to decrease the total amount of vehicles needed to deliver parcels to customers. Different ways of implementation in the transport network were presented, and optimal solution can be derived based on the current demand. Creating a new transport branch which combines ride-sharing apps and home deliveries shows promising potential for multi-functional vehicles which will result in decrease of the total number of vehicles in use. This system would need a platform where courier companies and passengers can request transport. This system would require a smart planning model which can combine both types of transport without increasing the transport times significantly. Future work will look into more design concepts for different vehicle size as well as more integrated approach in determining the optimal vehicle size based on the real-time demand for people transport and deliveries.

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