TRANSPORT EFFICIENCY OF DELIVERY TRUCKS: A STUDY OF COUPLING VEHICLE DESIGN AND TRANSPORT SYSTEM THROUGH FUNCTIONAL MODELLING AND OPTIMISATION

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ABSTRACT

To enable the emergence of new and efficient vehicle design from the transport system perspective, a formulation of a multifunctional vehicle-transport design optimisation problem is presented. System-wide measures of transportation and vehicle efficiency measures are conceptually considered in an integrative design approach to drive the transport solutions towards more resource-efficient and eventually more sustainable solutions. Considered efficiency measures associated with the system-wide aspect are namely, productivity and service efficiency, and measures associated with vehicle attributes are namely mass and shape efficiency. The conflicting nature of these measures is balanced using optimisation methodologies through multiple transportation scenarios with varying transport demand and deterministic drive cycles. The obtained optimisation results demonstrated that there is a strong interconnectivity between the vehicle's overall configuration and transportation aspects. Thus, conceptually demonstrating how the inclusion of various transport-vehicle efficiency measures simultaneously in an integrative design approach during the early vehicle design may yield a more efficient and better overall system performance.

Keywords: Design for X (DfX), Optimisation, Conceptual design, Resource efficient vehicles, Early design phases

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1 INTRODUCTION

The impact of the transport sector on the environment and energy demand has been in focus over the past decades. A strong correlation between the final energy demand and transport activities measured in tonne-kilometre has been highlighted in (European Commission, 2021). Nevertheless, since 2005 a relative decoupling between the sector's final energy demand and transport activities has been recorded and projected to continue and improve in the future. This decoupling is mainly driven by enhancement in the overall efficiency of various transportation modes (European Commission, 2021). This rate of improvement may contribute to the reduction of the total final energy demand of the transport sector until 2030 in the European Union (EU), but is not enough to maintain the decoupling trend for the longer term. Thus, stressing the need for improvement in transport efficiency, and more importantly resource efficient transportation.

The priority of maintaining the trend of reducing sector's energy demand while meeting the transport need of the society has significantly increased the challenges in vehicle design. Most of the literature has been focusing on improving the overall transport efficiency by finding optimum routes and fleet dimensions (Baldacci et al., 2009; Bookbinder and Reece, 1988; Liu et al., 2009; Pessoa et al., 2009) (vehicle types are known) and less research has been done on finding the optimum physical dimensions of the vehicles within a fleet (vehicle sizing) in early stage of vehicle design. The main argument is that, in real-life transport applications, transportation fleets are more often than not heterogeneous and including detailed vehicle and routing aspects in strategic fleet-management decisions is not always convenient (Hoff et al., 2010). In addition, it is argued that there is a high level of uncertainty in transport demands, travel time, and service time, hence it is not always straightforward to know what level of detail to include when making decisions (Hoff et al., 2010). In contrast, Ghandriz et al. (2021) argued that if a detailed description of a repetitive transport mission and the operational cycle is provided by the operators, including detailed vehicle and transportation aspects can be undertaken in an integrative transport planning to yield efficient and low-cost transport. Hence, Ghandriz et al. (2021) performed a mission-based optimisation of a heterogeneous heavy-duty vehicle (HDV) fleet by including detailed vehicle and transport design parameters. The approach showed that vehicle hardware can be meticulously tailored to best fit a known transportation mission. It was concluded that a more cost- and energy-efficient heterogeneous heavy-duty vehicle fleet may be configurated if the coupling between vehicle hardware, transportation mission and infrastructure are considered in the initial design stages. Nevertheless, the formulated optimisation problem became very large and complex due to a large number of model parameters. Thus, several sub-optimisation problems were formulated to address this. Furthermore, in the short-term run, the environmental performance of vehicles that function within a transport system can be improved by integrative design approaches such as multidisciplinary design optimisation (MDO) approaches (Bouchouireb et al., 2021; Martins and Ning, 2021). In contrast to conventional top-down design methodology that breaks down designs into several independent sub-problems with independent functional constraints leading to sub-optimal designs (O'Reilly et al., 2016), by MDO approaches, multiple aspects of a transportation-vehicle problem can be examined simultaneously yielding better system performance much quicker, cheaper, and more robust (Wolff et al., 2021). Conventional design methodologies are more convenient for industry applications, where engineers are grouped in a disciplinary-oriented manner working with complex engineering systems which makes the approach as the only perceived choice. However, the key principle of applying the MDO approach is that MDO considers various aspects and optimises a multidisciplinary performance metric with respect to as many design variables as possible simultaneously, finding the best trade-off between conflicting aspects of the formulated problem. The main challenge however remains during the early-stage vehicle design process and is further exacerbated by the division of the engineering design process driven by the lack of vehicle-specific knowledge faced by the vehicle designers (Lindahl and Sundin, 2013; O'Reilly et al., 2016).

To mitigate this challenge and enable efficient vehicle design, the integration of system-wide transport aspects and automotive aspects through several efficiency performances metrics is proposed. In the proposed integrative transport-vehicle design planning, vehicle design variables such as vehicle load capacity, vehicle length, and chassis stiffness (examines load-carrying performance) are considered. Single-mission transportation with deterministic drive cycle profile, deterministic transport demand, and loading and unloading velocity of goods as a function of the vehicle's load capacity have been considered as the transportation aspects. Furthermore, this integrated model has been used to maximise transport efficiency by using an optimisation methodology that balances the conflicting transport-related functions, which drives the early-stage vehicle design toward a more resource efficient vehicle design. This is achieved through formulating a multi-functional design optimisation problem to optimise the physical dimensions of a simple conceptual heavy-duty vehicle model. The influence of the structural characteristics of the vehicle is accounted for through its associated transportation performance. Thus, the overall objective of this work is to formulate a transportation-vehicle system that implicates the interconnection between transportation and vehicle configuration.

The major contribution of this study lies in the illustration of the coupling between the overall transport efficiency and the vehicle's physical dimensions. Such formulation balances the trade-offs and allows the emergence of new vehicle designs without tying to any specific mission or task and has a strong essence in multi-criteria decision making (Kijewska et al., 2019) for which, this study utilises the optimum vehicle design to maximise the overall transport efficiency without including routing problem. The design optimisation formulated here has an emphasis on conceptually illustrating the trade-offs in transportation-vehicle design.

This paper is organised as follows. Section 2 and 3 describes different building blocks of the formulated transport-vehicle model and used methodology. Section 4 presents the optimum vehicle configuration for four different predetermined freight transport demands and three different deterministic drive cycles followed by a brief discussion in Section 5. Finally, conclusions are given in Section 6.

2 MEASURES OF TRANSPORT-VEHICLE EFFICIENCY

The main purpose of transportation is to fulfil the demand for mobility (moving people, freight, or information) and this purpose is fulfilled by overcoming space which is shaped by a variety of human and physical constraints such as distance, time, and topography (Rodrigue, 2020). To date, there is no standard definition of what defines efficient transportation, whilst the emerging consensus indicates that economy, environment, and social well-being have a great impact on transport efficiency and sustainable transport system (Maheshwari et al., 2016). In other words, an efficient transport system not only involves socio-economic measures, but also involves the usage of resources, and the environmental impacts associated with transportation. Hence, vehicles and their overall efficiency have an important role in overcoming the environmental and economic challenges associated with the transport system. The main focus of this work is therefore to formulate the coupling between the transport system and vehicles in an exploratory manner rather than analysing economy aspects. Figure 1 illustrates the generic nature behind the coupling between vehicle and transport system through the vehicular functional model. It conceptually illustrates how vehicle sub-systems impact higher system measures. Although the physical manifestation of a transport system varies from one to the next, the elements of those systems can generally be chosen from a menu that is common to all, e.g. vehicles and infrastructure (Vanek et al., 2014). Thus, transport systems can generally be evaluated in terms of their function through various performance metrics of service, productivity, and efficiency. Similarly, vehicles may have their performance measured in terms of various efficiency measures (Vanek et al., 2014).

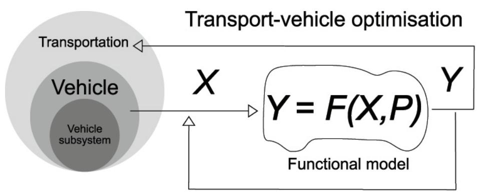

Figure 1. General schematic of transportation-vehicle-model

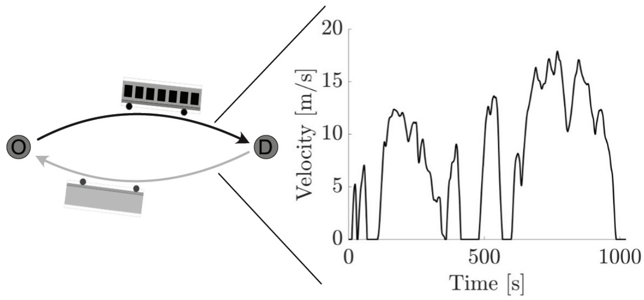

Figure 2. Repetitive single-mission transport assignment with known drive cycle profile

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The definition of efficiency is simply the ratio of output to the input expressed as a percentage (Larminie and Lowry, 2012). Expressing efficiency measures in percentage has a practical essence as the efficiencies in a chain of items can be multiplied to give an overall efficiency. For example, if a vehicle's nominal engine efficiency is 0.34 and supplying power through a transmission with 0.85 efficiency for which drives the wheels with a rolling efficiency of 0.8 then the overall efficiency of the combined system will be $0.34 \times 0.85 \times 0.8 = 23.12\%$.
Four measures of transport-vehicle efficiencies that couples system-wide aspects and vehicle design are considered here, namely, service efficiency and productivity which represent transportation aspects, and mass efficiency and shape efficiency which represent vehicle aspects. Thus, the formulation of overall transport efficiency with the inclusion of the physical dimension of a simple heavy-duty vehicle model may be expressed by

$$\eta_T(X) = \eta_{\text{Service}}(X) \times \eta_{\text{Productivity}}(X) \times \eta_{\text{Mass}}(X) \times \eta_{\text{Shape}}(X), \tag{1}$$

where $\eta_T(X)$ indicate the overall transport efficiency, $\eta_{\text{Service}}(X)$ denotes service efficiency, $\eta_{\text{Productivity}}(X)$ productivity efficiency, $\eta_{\text{Mass}}(X)$ mass efficiency, $\eta_{\text{Shape}}(X)$ shape efficiency, and X is the set of vehicle design variables. Each measure is discussed in more detail below.

2.1 Service efficiency

Service time is very important in many respects, mainly in terms of profitability (Ghandriz et al., 2021). In the work of Fu and Jenelius (2018), service efficiency of transport solutions has been examined through service time per shipment. Here in this work, it is suggested that service time may be optimised by finding the optimum vehicle configuration given a repetitive transport task with known drive cycle characteristics. It is also assumed that delivery vehicles are fully loaded from the warehouse to the customer and empty on return. The most straightforward indication of estimating the service time when loading and unloading freight is the size of the vehicle's load capacity (shipment size). Here it is assumed that loading and unloading time has a linear relationship with the load capacity of the vehicles, meaning one unit of freight takes one unit of time. The ultimate goal is to find the optimum ratio between service time and drive cycle time (driving time between origin to destination, OD pair). Hence, Equation 2 has been employed to minimise the service time. This is expressed as

$$\eta_{\text{Service}}(X) = \frac{T_{\text{OD}}}{T_{\text{OD}} + T_{\text{Service}}(X)}, \tag{2}$$

whereas T_{OD} denote the time for driving from a warehouse to a customer (OD pair) and $T_{\text{Service}}(X)$ denotes the time spent at customers loading and unloading freights. Here it is assumed that transportation assignments are repetitive with known drive cycle characteristics, according to Figure 2.

2.2 Productivity efficiency

The productivity of transport solutions can be measured by the number of deliveries a freight vehicle must take per transportation task. This measure captures characteristics such as available capacity in the system (Vanek et al., 2014). For example, assume a warehouse has a daily freight demand of 100 m^3, making a delivery vehicle with 100 m^3 load capacity the most productive transport solution since it fulfils its daily demand in one delivery run. In real-life applications according to Vanek et al. (2014), larger shipment quantities cost less on a per-unit payload than smaller ones. Consequently, there may be trade-offs between sending larger shipments infrequently with lower service efficiency, less expensive per payload unit and smaller shipments more frequently with higher service efficiency, more expensive per payload unit. To capture this trade-off, productivity efficiency can be formulated as the inverse of the number of deliveries and may be expressed as

$$\eta_{\text{Productivity}}(X) = \frac{1}{N(X)}, \tag{3}$$

where $N(X)$ denotes the number of deliveries as a function of the vehicle's load capacity. Figure 3 describes the example given earlier where number of trips needed to fulfil a daily freight demand of 100 m^3 by a single vehicle as a function of the vehicle's load capacity. It can be noted in Figure 4, the productivity efficiency (inverse of the number of deliveries) presents a discontinuous fashion since number of deliveries is integer. To address this discontinuity, productivity efficiency was subsequently

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obtained by computing the empirical cumulative distribution function (ECDF) of the data, then an exponential distribution function was fitted to these data and plotted as the dashed red line in Figure 4. This exponential function was then used as the surrogate model in the optimisation.

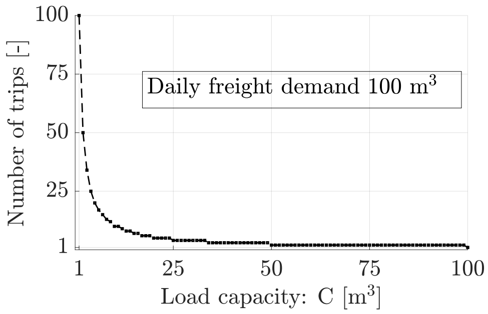

Figure 3. Number of trips required for a daily demand of 100 m^3

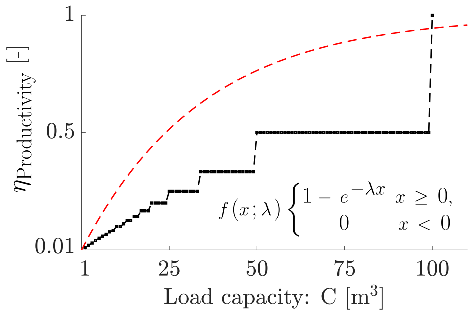

Figure 4. Productivity efficiency as the function of vehicle's load capacity

2.3 Mass efficiency

Mass efficiency is a qualitative ratio between the payload mass and gross vehicle mass and may be expressed as

$$\eta_{\text{Mass}}(X) = \frac{M_{\text{payload}}}{M_{\text{tot}}(X)} = \frac{M_{\text{payload}}}{M_{\text{payload}} + M_{\text{vehicle}}(X)}. \tag{4}$$

A basic decomposition of the vehicle gross weight may consist of only two-component. The first term represents payload, and the second term captures the necessary mass elements of the truck. e.g. chassis, drivetrain, etc. The underlying assumption of mass-efficiency stem from the energy efficiency point of view, and i.e. to determine how much energy is consumed to overcome mass-based resistances such as rolling and inertia resistance due to acceleration. Hence, mass-efficiency provides similar insight as energy efficiency without being tied to any specific power-train and upstream losses.

2.4 Shape efficiency

In this work, the cargo space of the delivery vehicles is assumed to be a cuboid. In an attempt to drive the vehicle design towards a larger cargo space without compromising the aerodynamic performance of the vehicle, Equation 5 is been employed. Equation 5 may therefore balance the trade-offs between practical aspects such as compactness and the aerodynamic performance of the vehicle with a cuboid and sharp-edged body. A good aerodynamic performance, here, implies vehicles with an appropriate aspect ratio. The shape efficiency measure is therefore modelled as

$$\eta_{\text{Shape}}(X) = \frac{V_{\text{payload}}(X)}{A_p L_{\text{path}}(X)} \tag{5}$$

where V_{payload} is the volume for which the payload is allocating, A_p is the frontal area, and L_{path} is the vehicle path length (length + height).

3 MULTIFUNCTIONAL MULTISCALAR VEHICLE-TRANSPORTATION MODEL

Vehicles may be described as multi-functional systems and must satisfy both the physical requirements of transportation (i.e. transport demand) and the statutory requirements to be approved for sale and use. To satisfy these requirements, the vehicle's primary function, i.e., to transport, needs to be decomposed on a functional basis and sub-models with sufficient model granularity must be introduced to examine different function performances of the vehicles. For instance, a modal analysis method may be used to examine the noise, vibration, and harshness performance, and a structure mechanic (FE model) model used to examine the crash performance. However, this may not reduce the complexity of the problem, but coupling different models into a simultaneous methodology with sufficient complexity balances the trade-offs between the functional performances of the vehicle. For example, a coupled model may balance the trade-off between aerodynamic and load-carrying performance.

As the focus of this paper is on exploring transport-vehicle efficiency, the complexity of the vehicular model, its functionalities, and the optimisation thereof, are purposely kept simple. To examine the functional requirement of the vehicle, a simplified chassis, a simplified suspension, and a payload with a constant density of 500 kg/m^3 have been elaborated here. The simplified chassis has a load-carrying function, and it is modelled as a simple beam with a certain second moment of area (to simply support the payload). The beam creates an explicit link between the vehicle's physical design and the overall efficiency performance of the transportation since the modelled beam has a certain mass which influences the mass efficiency measure, a cross-sectional area that influences the shape efficiency measure, and a certain length for which influences load-carrying performance, thus service efficiency and productivity efficiency measures.

The present multi-functional design formulation focuses on determining the vehicle's physical configuration given deterministic freight transport demand and deterministic drive cycle characteristics. The overall transport efficiency performance metric presented in Equation 1 is the objective of the optimisation problem that needs to be minimised. The design variables that influence overall transport efficiency compromise the vehicle load capacity (C), vehicle length (L), and vehicle chassis strength (EI) (beam's bending stiffness). Table 1 presents the general transportation-vehicle problem. The mathematical formulation for multi-functional design optimisation may be expressed as

$$\min_{X} \quad 1 - \eta_T(X) \tag{6a}$$

$$\text{s.t.} \quad T_{(I)}(X) \leq 0 \tag{6b}$$

$$T_{(E)}(X) = 0 \tag{6c}$$

$$X_{\min} \leq X \leq X_{\max}, \tag{6d}$$

whereas Equations (6b) and (6c) are the set of transport-related functional equality and inequality constraints, and X is the set of design variables. These acting constraints create warranties of different properties of the vehicle design, including mechanical, i.e., bending stiffness, aerodynamic, i.e., appropriate aspects ratio, and eventually other disciplinary fields. Although more functions and constraints may need to be considered in a realistic design, the constraints considered here are sufficient to fulfil the exploration as such. In this study, two functional constraints have been employed to examine the vehicle's overall performance. Firstly, one linear elastic loading response is used to incorporate the load-carrying function of the beam. The second functional constraint makes sure that freight transport demand is fulfilled. Verification that the bending displacement constraint is met is achieved by computing the linear elastic response via the Euler-Bernoulli equations. The maximum bending displacement selected for the first constraints is $\delta_{\max} = 10 \times 10^{-3}$. These two constraints may be given by

$$\frac{\delta(X)}{\delta_{\max}} - 1 \quad \leq 0 \tag{7a}$$

$$\mathrm{T}_{\mathrm{dem}} - N(X)C \quad \leq 0, \tag{7b}$$

where δ is displacement of the beam, $\mathrm{T}_{\mathrm{dem}}$ is the transport demand, $N(X)$ is the number of trips, and C is the vehicle load capacity.

Table 1. General transportation-vehicle problem formulation, which includes both transportation- and vehicle-design variables and parameters

Design variables	Design parameters	Objective function	Constraints
Vehicle load capacity (C), vehicle length (L), simplified chassis strength (I)	Vehicle width, wheel size, chassis mechanical properties, freight transport demand, drive cycle profile	Overall transport efficiency	load carrying performance, transport-related constraint

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4 RESULTS

The optimisation was performed considering three different deterministic drive cycles as operational cycles namely the first Worldwide Harmonised Light Vehicles Test procedure (WLTP first) shown in Figure 2, WLTP second, and WLTP third. All these drive cycles have different characteristics and driving distances providing a variety of driving characteristics. Each drive cycle was given five different daily demands of freight transportation in terms of volume, 100, 150, 200, 250, and 300 m^3. Hence, this simulation setup comprehends 15 different transportation scenarios providing enough data for comparative studies. The resulting optimum design variables as well as their associated objective function value, the total mass of the vehicles, and transport capacity measured in volume-kilometre are shown in Figure 5.

The resulting design variables, when only looking at one drive cycle but relatively increasing the daily demand of freight transportation, tends to solutions with larger load capacity. This has an explicit effect on the overall configuration of the vehicle. It indicates that, with a relative increase in the daily freight demand, vehicle lengths are more likely to become longer. Similarly, a vehicle's load capacity tends to become larger with higher freight demand. Looking at all the cases, 1% growth in freight demand gives an average rise of 0.13% of vehicle length on average. Similarly, this number of growths for load capacity is 0.26%. In addition, not only do vehicles become longer, but they become relatively higher also, i.e., the aspect ratios are also increased, indicating the balanced trade-off between mass and shape efficiency. However, looking only at one daily freight demand, but varying the drive cycles, the resulting design variables tend to be strongly correlated with the distance of the drive cycle as well, and hence time spend on the road, i.e., the longer the drive cycle distance, the larger load capacity and vehicle length. The largest vehicle load capacity, as could be expected, in the solution pertaining to the longest drive cycle.

The obtained second moment of area for all the investigated cases is sufficiently high and stiff to uphold the functional constraints of the beam. This has a significant influence on the mass efficiency measure, since the second moment of area effecting the mass of the beam with an order of four, and consequently the total mass of the vehicle. High enough bending stiffness ensures that the mass of the beam is minimised to uphold the functional constraint.

From the presented results above, it is clear that daily freight demand transportation and the distance characterised by drive cycles change the overall characteristics and physical dimensions of the conceptualised vehicle design, even though the vehicle model is very much simplified. While the actual resulting configurations themselves are perhaps unimportant, the fact that they do actually differ is of considerable significance.

5 DISCUSSIONS

A simple transport-vehicle efficiency performance metric implying the interconnection between the transport system and vehicle design has been presented here. This has been an enabler to an integrative multifunctional resource efficient-driven vehicle design. The formulation of the transport-vehicle model as a unified efficiency measure effectively handled the complexity that arise from the dimensional mismatch between transport and vehicle aspects. This means that the formulation allowed an equal comparison metric of the underlying dimension of the efficiency measures. For instance, the underlying dimension of service and productivity is time and number of trips which are two different dimensions. Hence, it was prerequisite to express the measures as efficiency measures to handle the complexity that arise from dimensional mismatch and providing an equal comparative metric. Furthermore, this formulation also prevented design domination. For instance, according to the formulation in Equation (4), a mass efficient vehicle would essentially meaning a vehicle with high aspects ratio and alone inclusion of this measure would effectively dominate the whole vehicle configuration. However, this dominance where balanced with other measures since they were expressed in same dimension. Similar issues has been discussed in the work of Bouchouireb (2023).

Moreover, the exploratory nature of the unified transport-vehicle model was illustrated through a simple vehicle model given various deterministic freight demand and drive cycles providing enough comparative data. Results here illustrated the coupling between the vehicle's physical configuration and the transport aspects (see Figure 5), providing a simple and yet comprehensive communication link between vehicle designer and vehicle consumers (operators). This means that more narrowed-down and

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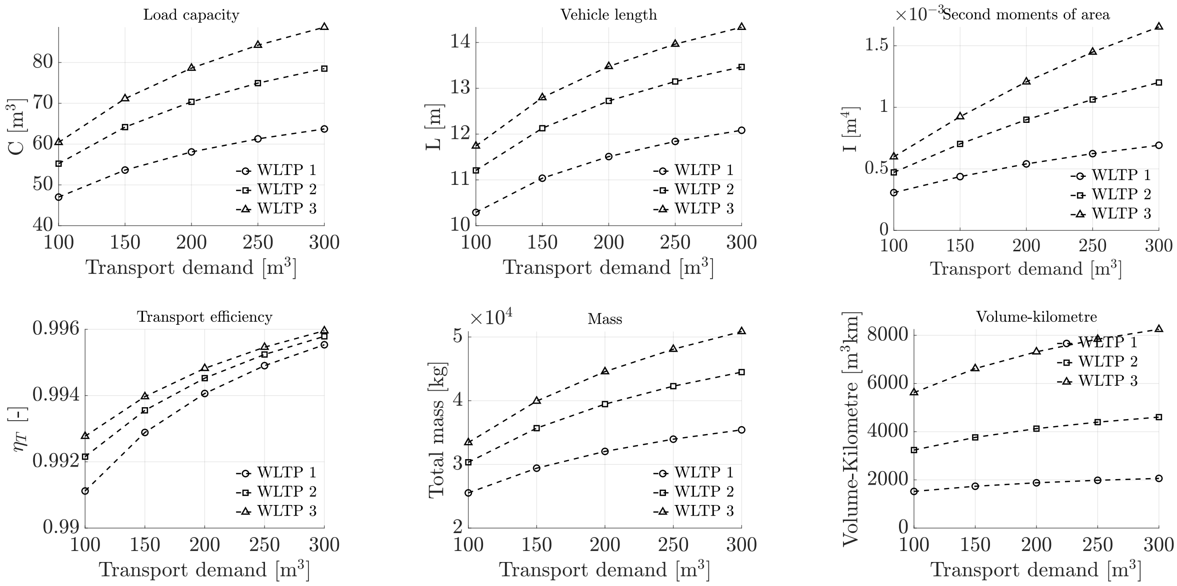

Figure 5. Resulting optimal design variables and the objective function values for all the 15 transportation scenarios. The following quantities are plotted against transport demand

resource-efficient vehicle may be derived if transport related information (from operators) is included in early-stage vehicle design. However, the research findings presented in this work require careful arguments concerning the cause of the results, and the conditions required by the results. These are discussed further in this section.

Likewise in any real-life application, the starting point for assessing the efficiency of the freight transportation in study was to maximise the usage of transport resources. Resources such as time, geographical distance, and vehicles constitute a central part of a general transport system. This argument is in keeping with the previous transport research studies, that efficient freight transport refers to the ability of deliver goods without wasting these resources, see e.g. (Fu and Jenelius, 2018; Anders and Benhard, 1997; Ghandriz et al., 2021). Hence, the modelling choices in this study stem from the transport demand perspective and maximisation of its resource utilisation. Furthermore, freight transportation demand was characterised in terms of volume and geographical distance (drive cycle distance), and the findings that there are strong correlations between vehicle configuration and freight transportation demand, and relative distance between OD are in line with previous studies Ghandriz et al. (2021).

In the study the modelling mass efficiency measure, similar to the modelling choice in Bouchouireb et al. (2019), stem from a mass-based allocation of the energy relative to rolling resistance and inertia resistance to acceleration. Contrastingly, the shape efficiency measure was modelled to ensure aerodynamic consistency, and also being consistence with practical aspects (e.g. shapes that fits into a warehouses). These two efficiency measures have shown conflicting characteristics. The design space was significantly affected by this conflicting representation for two reasons. Firstly, the mass efficiency measure drives the vehicle length to its minimum value to gain bending stiffness and to uphold the functional constraints with the minimum mass required. This however reduces the aerodynamic performance of the vehicle since the frontal area is increased to uphold the payload. Secondly, the shape efficiency measure drives the vehicle towards a more aerodynamically consistent shape, i.e., a longer and a smaller frontal area. In other words, the resulting optimum variable presented in this study partly explains the balanced trade-offs between these two measures.

Figure 5 shows how the optimisation results and the potential vehicle configuration changes if freight demand and drive cycle characteristics is varied. As expected, larger vehicle configurations corresponds to larger freight demand and longer drive cycles. Other studies has shown that, in general larger vehicle configurations are more cost efficient per payload unit (see e.g. Ghandriz et al. (2021); Wolff et al. (2021)). However, here it is also shown that larger vehicle configurations are potentially more transport efficient as well.

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As was stated in the introduction section, transport activities in the EU have been projected to continue and intensify in the close future followed by economic growth. According to International Energy Agency (2017), a 1% increase in GDP per capita gives rise to transport activities by 1.07% on average measured by tonne-km per capita. The finding and the model formulation in this study cannot be taken as evidence to address this challenge. Notwithstanding its limitations, this study does however suggest that integrating vehicle fleet sizing into the model formulation is convenient to meet these challenges of transport growth. Integrating such a model may comprehend the challenges of how many vehicles are needed to meet the growth in transport activities and what is the optimum configuration of vehicles within that fleet. In the context of fleet sizing, integrating economic measures such as total cost of ownership may contribute to comprehending the complexity of transportation solutions towards sustainability.

It should be noted that this study has been primarily concerned with static and deterministic drive cycles, i.e., the drive cycle does not evolve in time and is known in advance. In real-life applications operation cycles are more often than not deterministic and some degree of uncertainties are included. In the work of Hoff et al. (2010), it is argued that by ignoring routing aspects, vehicle/fleet design may be based on a too-simplified view of freight transportation demand. Since the findings of this study indicated a strong correlation between freight transportation demand and vehicle design, integration of routing aspects in vehicle design is left for further research. Agent-based simulations are highly relevant methodologies to address this integration with the inclusion of uncertainties in demand, travel time, and service time.

6 CONCLUSIONS

In this paper, an initial exploration of transport efficiency measures based on transport resources has been presented. A simplified truck model was studied and optimised to balance the trade-offs between the presented efficiency measures. The optimisation results have successfully shown that there are strong correlations between vehicles' overall configuration and transportation aspects, although in real-life applications routing aspects and freight transport demand are not predetermined. The vehicle model considered here was very much a simplified vehicle model and the fact that resulting optimum vehicle configurations differ, was considered of significance. The optimisation was successful in achieving a vehicle configuration that maximises the overall transport efficiency whilst upholding the functional constraints. Future work is needed to integrate economy measure to gain insights of how economy aspects may impact the vehicle configuration. Also, future research includes to study the design sensitivity when lettering uncertainty propagating through transport-vehicle model.

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