Dynamic freight fleet modeling

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Abstract

Freight traffic and functioning logistic systems are basic prerequisites for a successful economy. The combination of behavioral changes towards online shopping and the resulting need for high delivery flexibility will lead to a growing demand of light duty vehicles (LDV). Despite already existing models which predict the size of the LDV fleet based on a given transport demand, a dynamic connection between transport demand and vehicle fleet has not yet been realized. A distribution of annual mileages from LDVs, which have a wide range, leads to the assumption that fleet operators could adapt their mileage within set limits. This dynamic mileage adaptation is expressed as a module, which can then be integrated into existing fleet models. The results show that the number of LDVs needed to satisfy the demand is less volatile compared to the use of constant annual mileage. The results can certainly be seen as one step to more realistic fleet forecasting, yet further research in the field of fleet operator behavior would be beneficial.

Introduction:

The freight transport sector itself can be divided by different traffic modes. In addition to the road and rail sectors providing services on land, intercontinental material flows are mostly operated by marine and/or air transport services. The majority of freight is carried by trucks or light duty vehicles (LDV), due to the greater degree of flexibility provided through road traffic. In countries such as Germany, where business to customer distances are rather short, the share of road traffic increases (see figure 1). In combination with the behavioral changes towards online shopping and the resulting need for high delivery flexibility, the demand for road freight traffic will increase in the future.

Increasing transport demand leads to an increase in the number of vehicles needed for freight service. Most models that are used to predict transport performance and fleet development assume an inelastic connection between transport demand and the size of the fleet. Initially, this assumption seems to be plausible. As a first step to dynamic fleet modeling, this paper tries to expand upon existing models that focus on an inelastic connection between transport demand and fleet development, by integrating a dynamic adaptation of the annual mileage driven by the vehicles. Therefore, the base assumption is that the freight carrier attempts to match the transport demand by optimizing the use of the already existing fleet.

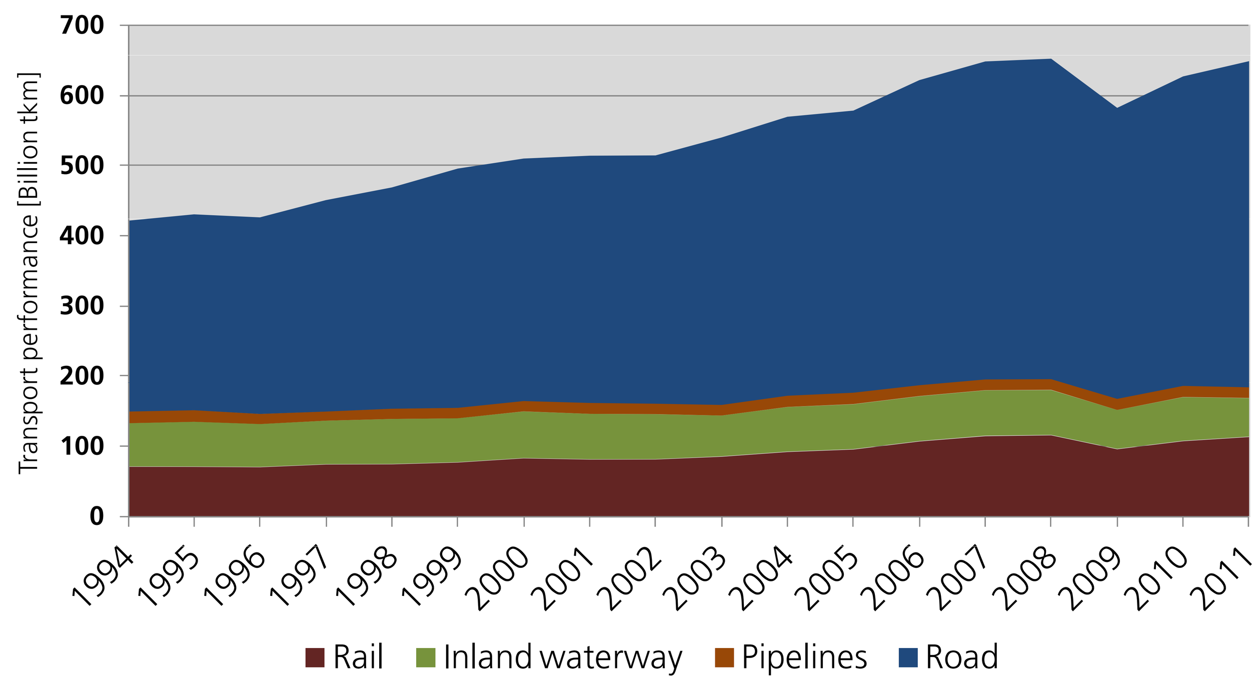

Figure 1: Development of the Transport performance by mode in Germany (DIW 2013)

Methodology and model description

Database:

A first step to a closer understanding of the fleet composition was the creation of a sample of **used LDV sales with a sample size of 3,000** (TruckScout24 2012). By using the first registration date of the LDVs in combination with the current mileage in kilometers, it is possible to calculate the **average annual mileage**. The box plot of the statistical distribution is published in figure 2.

- **Median:** The median that divides the distribution into two equal parts of 50% lies at **16,646 km**.
- **Mean:** The median is just below **the mean with 20,024 km**
- **Quartiles:** The first quartile at **11,429 km** and the third quartile at **24,108 km** limit the box plot.

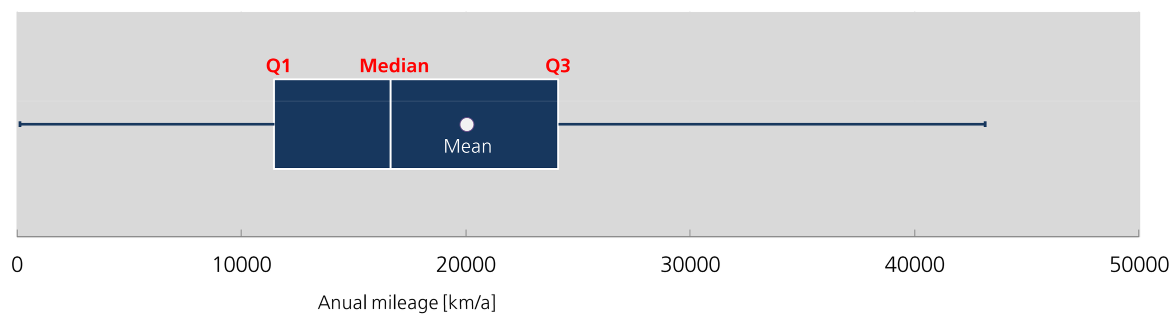

Figure 2: Box plot of the annual mileage distribution

Modeling structure:

The fleet module calculates the fleet growth based on the LDVs needed compared to the current fleet. The current fleet itself influences on the number of needed LDVs by multiplying with the adapted annual mileage to get the current transport offer. Without the annual mileage adaptation the number of needed LDVs to satisfy the transport demand is calculated based on a constant average annual mileage. Therefore, there is a direct correlation between this variable and the changes to transport demand.

In order to reflect the dynamic behavior of fleet operators, a dynamic annual mileage used in the fleet module seems to be more realistic. Based on the transport demand, the yearly delta transport demand can be calculated. This indicator influences on the delta annual mileage which will be needed to satisfy the transport demand with the current fleet. Depending on the value of the delta annual mileage, the current mileage will increase or decrease in order to adapt the present fleet on the changing circumstances. The dynamic of the adaptation is specified in the variable adaptation speed lookup which is determined by the chosen scenario . After that, the annual mileage changes can be calculated. These calculations are based on the behavior change of the freight carrier and the resulting number of needed LDVs.

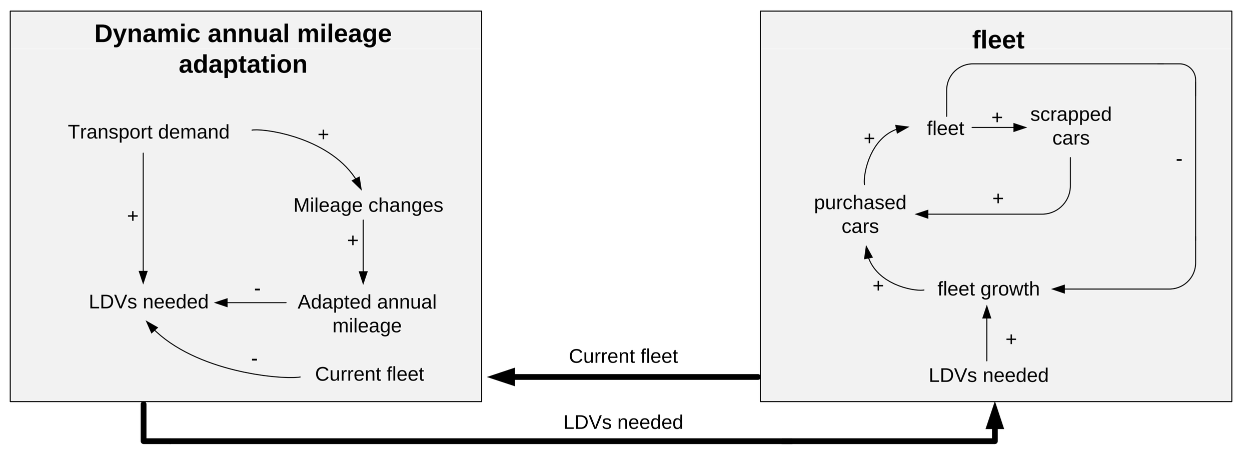

Figure 3: Model structure, interaction of the two modules

Dynamic mileage adaption

The major challenge of this module is represented by the adaptation speed, which influences the adaptation rate significantly. As already mentioned, the distribution of the annual mileage differs considerably. As a realistic starting point, the median of this distribution is regarded as the best fitting value. The major question is how the freight carriers could change the annual mileage in order to adapt different developments of transport demand. The baseline idea was that the capability to adapt declines as the distance to the median increases. One first assumption was that due to framework restrictions, an adaptation is only possible between the first and third quartile. Taking into account that the restrictions for most freight carriers could be the limiting factor, it seems to be more likely that fleet operator would lower their mileage only down to the average value between median and first quartile. Below this threshold value freight service could be unprofitable, thus the adaptation rate will drop to zero and the annual mileage will not change anymore.

$$A(x) = \begin{cases} 0 & \text{if, } p(x) < (q_1 + m)/2 \\ 0.00038 \cdot x - 5.38 & \text{if, } (q_1 + m)/2 \le p(x) < m \\ 1 & \text{if, } p(x) = m \\ -0.00027 \cdot x + 1.45 & \text{if, } m < p(x) \le (q_3 + m)/2 \\ 0 & \text{if, } p(x) > (q_3 + m)/2 \end{cases}$$

where

$A(x)$ = adaptation speed function
$p(x)$ = mileage distribution
q_n = n- Quartile
m = median

Equation 1: dynamic mileage adaptation

The mean value of this distribution was used as the upper limit to take respect to the fact, that there will be a few freight carriers which are able to vary the annual mileage up to relatively high values. Equation 1 shows the complete adaptation rate function as a discontinuous defined function which drops to zero below and above the defined limits. As a curve form a linear relationship was chosen, knowing well, that other relationships could also be possible.

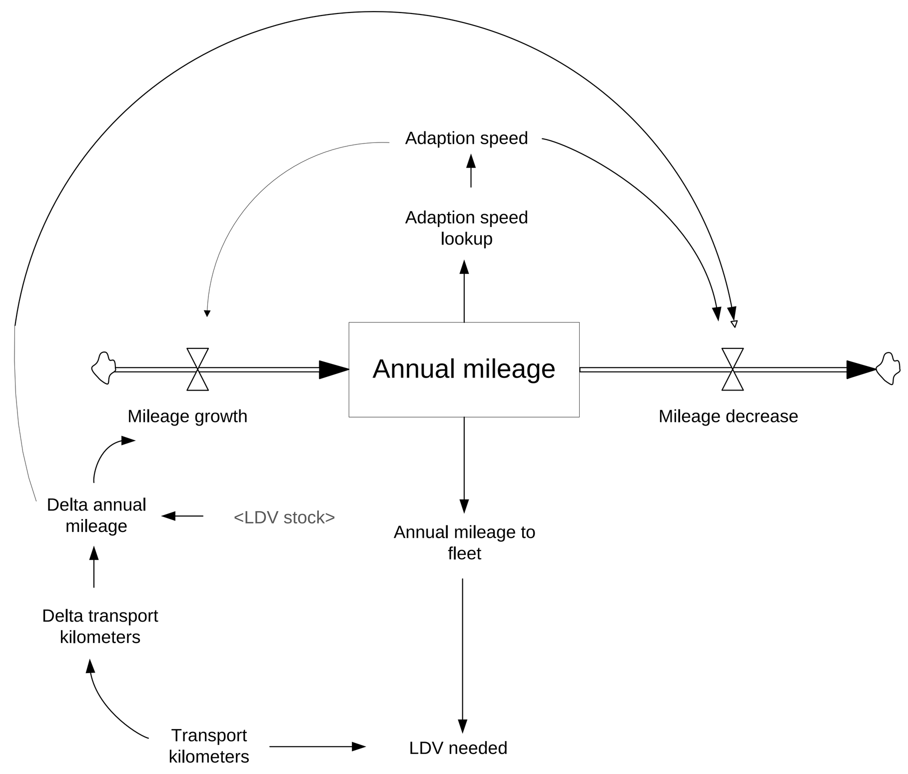

Figure 4: dynamic mileage adaptation

Simulation results

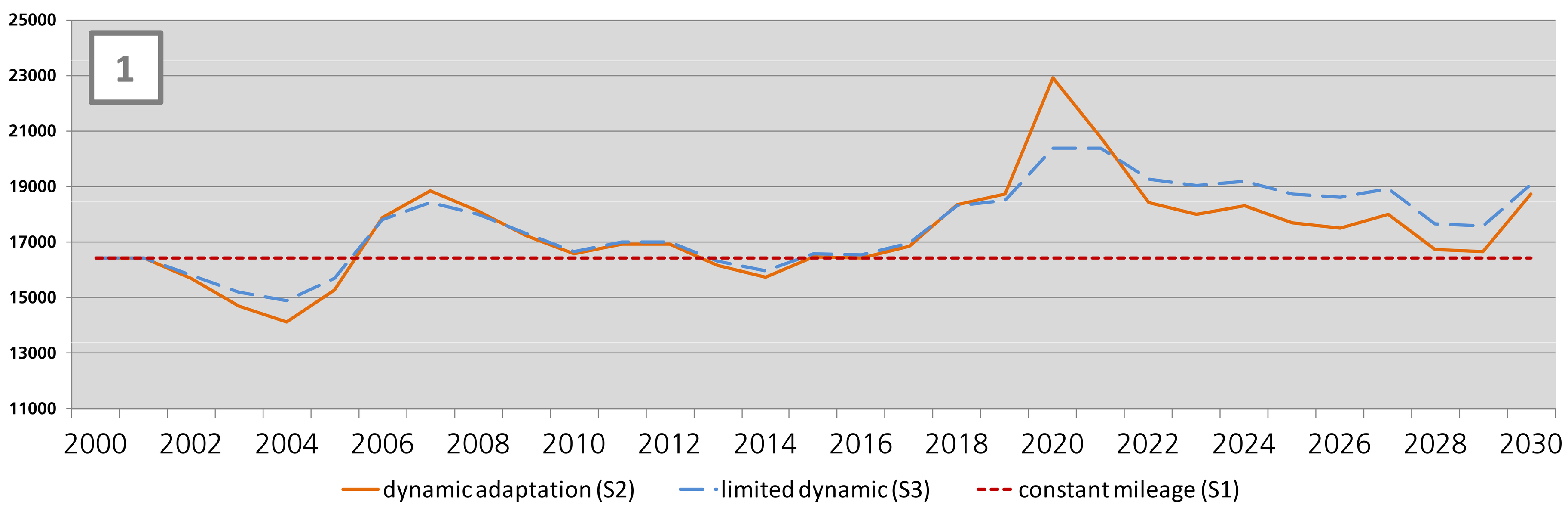

Figure 5: development of the annual mileage

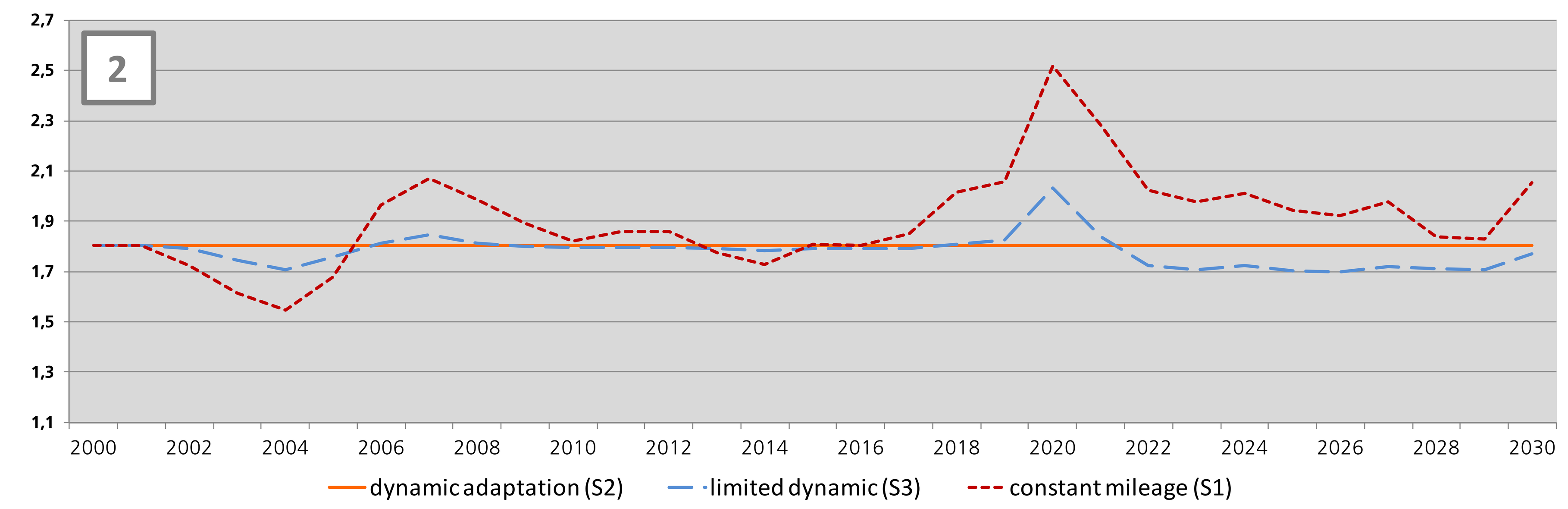

Figure 6: development of the number of needed LDV

Scenario 1: constant mileage

This scenario does not allow any dynamic mileage variation. The connection between transport demand and transport offer is completely inelastic.

Scenario 2: dynamic adaptation

The second scenario allows a dynamic adaptation of the annual mileage taking into account the fact that freight carriers change their behavior. Within this scenario the dynamic adaptation process is unlimited.

Scenario 3: limited adaptation

Constraint variations of the freight carriers lead to a limited adaptation of the annual mileage within certain borders.

1 An important aspect is the difference in adaptation speed, which can be seen in the early development (2003 till 2004). According to less dynamic adaptation due to higher variations from the median, the changes of the annual mileage remain on a lower level than in scenario 2.

The first scenario with its non-dynamic development of the annual mileage leads to constant values remaining on the same level during the whole observation period. As a whole, the dynamic adaptation of the annual mileage, depending on the degree of limitation, allows for a variable adjustment of the fleet usage to the transport demand.

2 The second part of the results is formed by the implication of the mileage adaptation on the actual number of LDVs needed to satisfy the transport demand. The completely inelastic connection between transport demand and the number of LDVs needed explains the shape of the curve of scenario 1 (see figure 9), which is as volatile as the transport demand itself.

With the complete dynamic adaptation from scenario 2, the number of needed LDVs remains stable on the same level as the mileage varies according to the transport demand. Thus, the fleet size will remain the same as the operators could adapt the mileage to satisfy different levels of transport demand. The delayed and only partly dynamic mileage adaptation of scenario 3 leads to a curve basically oriented on the results of scenario 2. The lower adaptation speed induces a less volatile number of LDVs needed. Another effect is that in case of increasing annual mileage, the lower adaptation speed implies that the mileage will remain on a high level. Therefore, the number of LDVs needed drops below the value of scenario 2.

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