Backcasting in freight transport demand modelling – chances and challenges

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Abstract
Freight transport demand models are important tools to support policy decision-making by enabling decision makers to evaluate transport policies and correlated effects. This significance puts high pressure on freight models regarding their accuracy. In order to ensure model accuracy there are different methods within the wide area of quality assurance that can be applied. Although backcasting is such a method it is, however, often neglected or implemented insufficiently. The paper presents major challenges and chances occurring from backcasting that have been conducted using a state-of-the-practise freight model. It reveals that backcasting is not easy to handle – especially referring to data availability and quality. Serious challenges emerge regarding availability of consistent input and output data as well as goods classification. A guideline, deduced from the experience in application, is presented to assist practising backcasting in freight modelling.

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1. Introduction

Freight transport – as a derived demand from trade – is of major importance to the economy. Due to changes of structural economic conditions (like increasing international trade) it is still increasing and a further increase of freight transport is forecasted worldwide (Woodburn et al., 2008). The ongoing increase in freight transport induces the need for an accurate estimation of these movements and the underlying commodity flows – especially for future (Chow et al., 2010). Therefore, understanding the demand for freight transport is essential in order to analyse impacts on and interactions in the freight transport system. Since decades, considerable efforts have been conducted to progress in that field. Furthermore, existing key issues in freight transport policy are increasing the need for tools to support effective decision making (Winston 1982, Tavasszy 2006, Ben-Akiva et al. 2013).

Freight transport demand models are such tools. They can be used to support decision-making by enabling decision makers to evaluate transport policies and correlated effects (Tavasszy & de Jong, 2013). Detecting changes in freight transport and forecasting future demand provides an important basis for transportation planning (Chung & Kang 2013). Nevertheless, implementing and adjusting is not just straight forward (Turnquist 2008). Freight transport models already emerged in transport science in the early 1960s but, however, their development and application took of much slower in comparison to their passenger transport counterparts (Tavasszy & de Jong, 2013). Since then, numerous models have been developed in the past to provide an adequate basis for decision-making (see e.g. Tavasszy 2006, Chow et al. 2010 or de Jong et al. 2012).

However, developing freight models is more complex than the development of passenger transport models as there is a much greater diversity of actors involved in decision-making in freight transport (e.g. shippers, carriers, intermediaries or operators) and more diverse objects to be transported in diverse vehicles. Furthermore, causes of transport, time and spatial structures as well as constraints differ significantly. Limited data availability is a major challenge in the field of freight modelling as well. Therefore, the majority of freight transport models additionally need to use simplistic assumptions for computation (de Jong et al., 2012).

In order to determine transport demand different model types are used (e.g. truck-based models, commodity-based models, delivery-based models, economic activity models and some mixed types). A detailed classification and description of different model types can be found in de Jong et al. (2004). There are also lot of reviews regarding the different model types, their application and their dis-/advantages (see e.g. Eastman 1980, Winston 1982, Chow et al. 2010, de Jong et al. 2012, Comi et al. 2012, de Jong et al. 2004). Depending on model intention and data availability different model types are used for impact assessment (see e.g. Tavasszy & de Jong 2013).

The growing demand for better quantitative impact assessment of policy measures generates an increases pressure on transport modelling. Although freight modelling is relatively young compared to passenger transport modelling, decision makers raise similar claims to accuracy of freight models. It is important to decision-makers to understand capabilities and limitations of models in order to evaluate the impacts of transport policies (de Jong et al., 2012). Thus, accuracy and reliability of freight models is crucial for realistic transport policy assessment (Chung & Kang, 2013). There are different methods within the wide area of quality assurance (QA) that can be applied to ensure model accuracy.

Backcasting – the process of conducting a retrospective analysis for a "forecast year" that lies back in the past and comparing model results to surveyed data – is such a method. This process is, however, often neglected or implemented insufficiently. There is only a small number of field reports on backcasting and one reason may be found in the absence of consistent and standard methods or rather guidelines to conduct backcasting. Towards finding an answer to the question of how to conduct backcasting in a sophisticated way several other research questions occur: How to delimit backcasting in the field of quality assurance? What are important parameters to consider and what do these parameters tell us? Which data to use best for backcasting? What challenges do occur within the process and how to handle them best?

In chapter 2 we will show that literature research will not bring us close towards answering all the raised questions since not many studies have been published. It merely allows the delimitation of backcasting to a certain degree as well as elaborating important interfaces with other methods of QA. We will present what has already been done on the topic as well as existing research gaps and address core themes – like linking the backcasting method with other methods of quality assurance, which will show that backcasting is only one important issue in QA. In order to investigate the topic in more depth and to reveal useful recommendations we chose to practise backcasting using a state-of-the-practise freight model. We will present the used literature and data in the subsequent chapter (research setting). Furthermore, we will describe the model we used to examine backcasting. Chapter 4 presents the major findings of our research. It reveals that backcasting is not easy to handle. Moreover, we will present a guideline for "good backcasting practise" deduced from the experience in application. In the discussion chapter the central results of our study are compared to as well as integrated into the context of previous research that has been conducted so far. A conclusion will close the paper and give an outlook to future research possibilities.

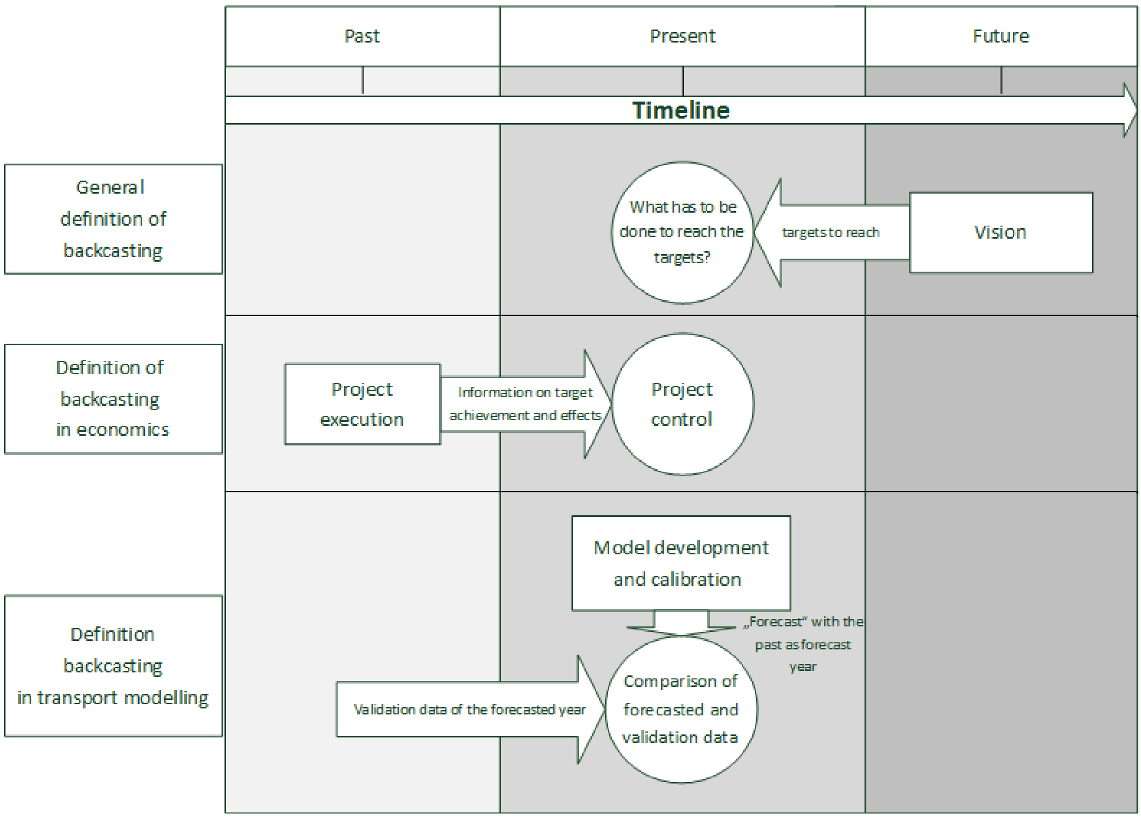
2. State-of-the-art: backcasting in transport science

The term quality assurance (QA) is widely used and spread over several disciplines. It mainly serves to achieve and preserve a predefined quality (Voigt, 2014). Due to the fact that developing transport demand models is a very extensive process, the assurance of high quality is very important in that manner (Leerkamp, 2010). The method of backcasting plays a significant role within the QA because it sheds light on the quality of a models' capability to forecast transport demand.

Backcasting[1] is a method that is not only used in transport science, but particularly in economics. It is defined as ex-post examination of projects or events (Wohltmann & Wübbenhorst, 2013). In most cases the overall goal is the examination of target achievements or effect analysis.

In transport, backcasting is mostly used to determine policy in order to meet future end points (see figure 1) (Barella & Amekudzi, 2011). However, in transport modelling backcasting is considered as the ex-post examination of a "forecast year" that lies back in the past. Based on surveyed input data for the forecast year, a retrospective forecast – backcast – is accomplished. The model output is then compared to observed data/statistics of the "backcast year" (Sammer, 2010). Figure 1 contrasts the different definitions of backcasting in order to delimit the terms.

Figure 1: Definition of backcasting relating to its time scale



[1] The term "ex-post analysis" is also used synonymously for backcasting in some contexts.

Conducting the backcasting method requires a fully established model that has passed all relevant model steps like model estimation, validation as well as plausibility checks and model evaluation. Backcasting itself can also be classified as an instrument within the field of plausibility checks[2] and validation[3]; it checks plausibility of forecast results and, therefore, contributes to model validation.

In literature, backcasting is described as excellent and high-quality instrument to evaluate model quality and their forecast capabilities (Gunn et al. 2006, Sammer et al. 2012). Regardless its high value for modelling, there is hardly any literature and, furthermore, existing examples are rarely found (Roorda et al., 2008).

In Germany for example, there are no rules and standards for backcasting analysis procedures, documentation or quality of data (Leerkamp, 2010). One of the most important works can be found in a code of practice compiled and published within the project "QUALIVERMO"[4] (Sammer et al., 2010). The project revealed that the time span between reference and forecast year should not fall below a lower limit so that changes are big enough to determine reactions of the model. The code recommends a minimum difference of ten years (Sammer et al., 2012). Furthermore, it has to be assured that sufficient data are available for the backcasting year – regarding input as well as validation data. The following sequence is recommended in order to conduct backcasting:

1. Modelling the reference year
2. Determining input data and check-up data for demand for the backcast year
3. Modelling the demand for the backcast year (based on the reference year)
4. Comparison of modelled and observed transport demand (and changing model parameter if congruence is insufficient + repetition of step 3)
5. Documentation und interpretation of result (Sammer et al., 2010)

In some other countries, like Great Britain or the United States of Amerika, some studies and basic rules can be found (see Gunn et al., 2006; Cambridge Systematics, 2010). One of the few studies dealing with backcasting was conducted to validate the National Transport Model (NTM) for passenger transport in Great Britain (Hernandez, 2012). Starting from the base year 1998 two past years were examined (1991, 1976). Referring to point 4 of the recommended sequence in backcasting, choosing reasonable data is an important issue to compare model results with reality. For the NTM different aspects like mode choice, distribution of travel distances or number of trips were investigated for different groups and regions (Gunn et al., 2006). However, the main focus of the ex-post analysis is on typical passenger transport related indicators.

Beside the demand data that were used to evaluate the NTM, for instance, there are particular evaluation indicators that are commonly used to interpret forecasts such as: transport volume,

[2] Subsequent step conducted after model estimation. The step is necessary to provide proof that the model reproduces reality in an adequate manner. It is intimately connected to plausibility checks.

[3] Model results are always defective and, thus, model precision is limited. Therefore, model deviation has to be applicable (plausible). This can also be ensured by testing the model's reaction to changing input data by means of fictive scenarios, sensitivity analysis and backcasting (Sammer et al., 2010).

[4] „Qualitätssicherung für die Anwendung von Verkehrsnachfragemodellen und Verkehrsprognosen". Paraphrase from the original German name: quality assurance for the application of transport demand models and transport forecasts

transport performance, travel distance, confidence interval, and comparison with traffic count data, difference analysis, consideration of averages, median and skewness of distributions (Lange, 2014).

Although there are some recommendations to conduct backcasting because of its importance for model validation and quality assurance in general, there are no field reports or other studies that report experiences from backcasting. Furthermore, the found literature on QA does shed light on backcasting in a more theoretical way so that there is no recommendation or guideline on how to conduct a backcasting analysis for freight transport demand models.

3. Research settings

The used freight model

Although there are different approaches towards freight transport modelling the state-of-the-practise is, however, the aggregate four-step modelling framework that was initially developed for passenger transport modelling (Samimi et al., 2014). This modelling structure follows a sequence of four steps (generation, distribution, modal split and network assignment). It has been adapted to freight transport modelling – although additional steps are often needed, for instance, to transform trade flows to flows of goods and further into vehicle flows (de Jong et al., 2012).

The four-step approach and/or extended versions of the four-step model are currently state-of-the-practise in most cases of application, which is justified because building up a detailed freight model requires detailed information on freight transportation. The more detail is required, the higher the data requirements get. Due to high data requirements, the scope or the accuracy of the research mostly becomes more limited due to resource limitations. In contrast, standardised data are commonly available for macroscopic models on national scale. Thus, using a freight transport model on a national perspective offers the opportunity to utilise reliable statistics gathered on national scale. Although there are no statistics on logistic chains in Germany, data for all transport modes are available. There is also information on transport between states, which can be used for the calibration and validation. Furthermore, statistics are commonly gathered on a regular basis, which also helps to evaluate the results of backcasting. For these reasons, we used such a state-of-the-practise model to test backcasting and, thus, reveal useful recommendations.

The used model (see Müller et al., 2012) offers a macroscopic view on freight transport on national scale (NUTS1-NUTS3) for Germany and includes all surface transport modes (road, rail, inland waterway). Transport to all European countries is also included on aggregate level (NUTS 0) as well as global trade through considering seaports and airports. The model is a commodity flow model that is based on an extended four-step modelling process including freight generation, combined freight distribution and mode choice, trip conversion and traffic assignment. Within the model 60 business branches are distinguished. They are related to the transport of 20 types of

commodities (NST 2007). The multimodal approach allows a choice of 12 means of transport on road, rail or inland waterways. Model estimation for mode choice and freight distribution is achieved using an evolutionary algorithm (particle swarm optimization – PSO). Furthermore, the model also distinguishes between loaded and empty runs.
More detailed information on the model can be obtained from Müller et al. (2012). The chosen model structure matches with the structure for commodity flow based models described by Chase et al. (2013). It is recommended for the utilization on macroscopic level and for national transport models.

Setting the scene

The model described above has been calibrated to the base year 2008. With respect to the recommendation of a period of at least 10 years between the calibration and backcasting year, the year 1998 was chosen as backcasting year. Referring to that choice, we knew that there could be certain influencing factors, which hamper a straight forward analysis. Data could be influenced by irregularities due to the economic crisis, for instance. Furthermore, the change of commodity classification in 2007 was well known, even though its impact on the evaluation could not be estimated.
However, the definition of the backcasting year should be closely connected to the availability of input- and evaluation data, which are needed to evaluate model outputs. Data availability is already known as a major challenge in freight transport modeling in general, but this challenge applies in particular for backcasting since availability of proper data does not remain constant over time. In addition, there is an important dichotomy of data utilization: data that have been used for model calibration cannot be used for evaluation of the model. Thus, independent data must be used for model evaluation because they have a higher explanatory value concerning the model's consistency.
The analysis of German data sources revealed that a lot of data, which could be used for model evaluation, are not available. One reason might be the fact that the forecast year dates back ten years, so that some of the data might not have been measured.
Within the analysis, the following sources have been used:

- Statistisches Bundesamt Onlinedatenbank (Translation: Federal Statistical Office) [Statistisches Bundesamt, 1998]
- Kraftfahrtbundesamt Datenbank (KBA) (Translation: Federal Office for Motor Vehicles Database) [Kraftfahrtbundesamt, 1998]
- Kraftfahrzeugverkehr in Deutschland (KiD) 2002 (Nationwide Mobility Inquiry) [Bundesministerium für Verkehr, 2002]
- Verkehr in Zahlen (ViZ) (Translation: Traffic in numbers) [Deutsches Institut für Wirtschaftsforschung, 2000]

The following table shows the data availability.

Table 1 Data for backcasting analysis

Description	Availability
Freight receiving and transmission per German state	yes
Freight distribution matrix	since 2005
Travel time distribution	-
Vehicle speed	-
Travel distance distribution	ViZ: 1999
Transport performance	KiD 2002, ViZ
Vehicle miles / total vehicle miles	just street transportation
Mean transport distance	KiD 2002, ViZ
Number of trips	just street transportation
Traffic counting	just a few states
Number of empty trips	just street transportation

Due to missing freight distribution matrices, there is no way to evaluate the results of freight distribution. Time depending distributions and velocities are not available as well – although these data would be great as they are presumably in the most cases independent data.
Referring to the evaluation data, the model's output data need to be respected as well. In this case, the step of network assignment has not been calculated as it will be done by commercial assignment software. Thus, the evaluation will base on OD-matrices, which result ether from mode choice (unit: transported tons per relation) or from trip generation (unit: trips per relation). In connection with cost matrices (e.g. distance, travel time or costs) per relation, the parameters above can easily be measured.

4. Lessons learned

The results of the backcasting can be divided twofold. First, the chances and challenges, which occurred during the practical work, are shown. Afterwards, the methodological and operational chances and challenges of the backcasting method will be illustrated. Finally, a guideline will be elaborated out of these findings.

Aspects to be measured by backcasting

As described above, the number of available input and validation data is the most import issue in the context of backcasting. Depending on the data availability, a comparison of model results and actual data can be conducted for each module. In this work, a separate analysis of freight generation was achieved by observing the produced tons of each transport zone. The causes for deviations can be determined more easily, in this way. When working with advanced modules, which base on previous modules, this approach becomes less explanatory. This conclusion can be seen as one of the main aspects of the backcasting method: Just in special cases, the validation of data can be used simultaneously for evaluating the cause of error.

In further steps, final model results were compared by general German-wide parameters, which are

- transport performance,
- transport distance distribution,
- number of loaded and empty trips.

In contrast to the previous section, these data cannot immediately help to identify model errors. Nevertheless, it can be observed if the development of each of the parameters as well as in relation to each other is predicted correctly.

Additionally, the predicted data, the validation data and the data of the analysis year can be used to calculate a confidence interval. This confidence interval can be used to state the reliability of a model's forecast. However, when conducting backcasting for one year, the confidence interval relies on just two mesh points, only.

Challenges

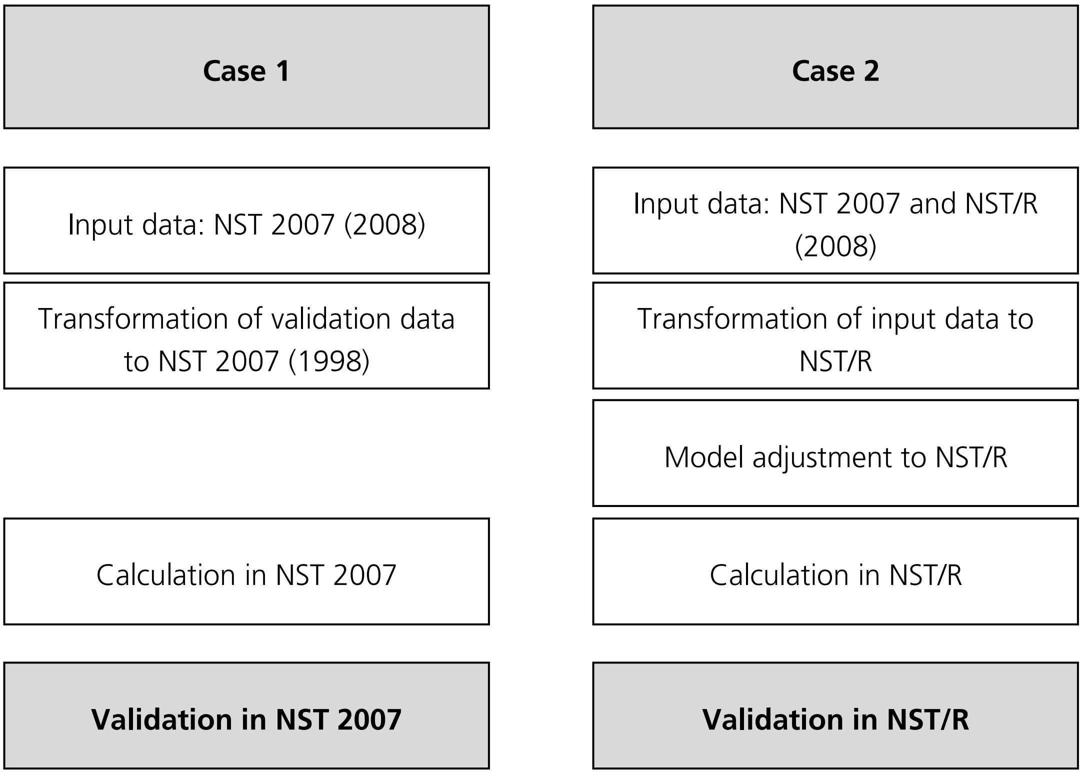
As the issue of data availability and quality was claimed a couple of times, the existing challenges are described in the following section.

In best case, all the output data, which are calculated within the freight transport model, are available as validating data in the forecasted year, divided by commodity, transport mode and for each relation.

As expected, these data are not available – in particular not for the past ten years. However, the data form the basis for the backcasting method so that the evaluation was conducted with the help of aggregate data.

Furthermore, the unification of transport statistics in the European area brought a serious change of data classification, which is a huge challenge. The change of commodity classification was realised in 2007 and leads to different classifications in the analysis (2008) and the backcasting year (1998). Whereas the data of 1998 are classified by NST/R, data of 2008 are classified by NST2007. This leads to the challenge to decide, which of the classification should be used for validation. The following figure displays both options and its needs of transformation.

Figure 2: Calculation steps depending from commodity classification



The existing transformation key from NST/R to NST2007 is based on a very fine level of data classification which is more detailed than the actually used data. Therefore, there is the need to develop another transformation key, which leads to additional errors. Finally, we determined that the validation is conducted in NST/R due to the fact that expected errors, in this case, are less important. Moreover, the validation data are kept free of errors.

Important aspects when conducting a backcasting

When looking at the process of the backcasting methods, different methodological questions arise. An important one is: from which source should the input data for the forecast year taken from? There are two existing approaches:

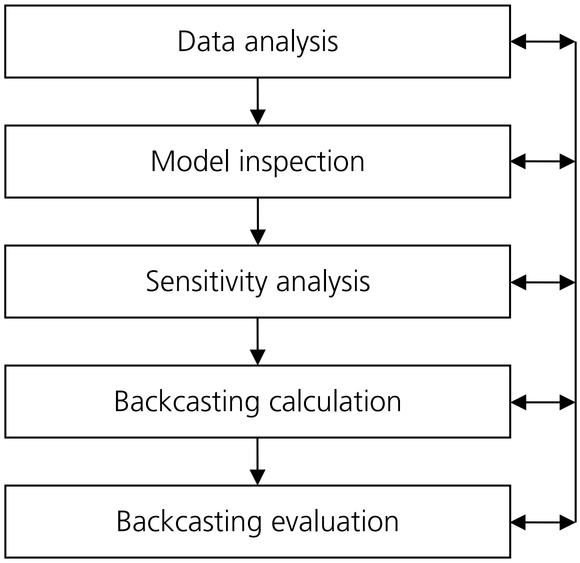
- **Empirical data**: The input data that are especially relevant for freight generation are those, which actually occurred in the forecasted year. Thus, the model itself can be validated; Errors do not arise from incorrect input data.
- **Prognostic data**: The input data are determined the same way like for forecasts (to the future). Thus, the calculation of input data becomes part of the backcasting analysis.

We decided to choose the approach separately for each input parameter depending from its importance for the model results and due to the chance to evaluate the difference between empirical and prognostic value.
Another important question is, which backcasting year should be chosen. The data analysis has shown that unforeseen incidents like the world economic crisis can arise. Additionally, unexpected high or low values – so called runaway values – might appear. Furthermore, the already described change of commodity classification must be respected. Factors like these must be considered, combined with the guiding value of a minimum of 10 years in difference.

5. Guideline for backcasting

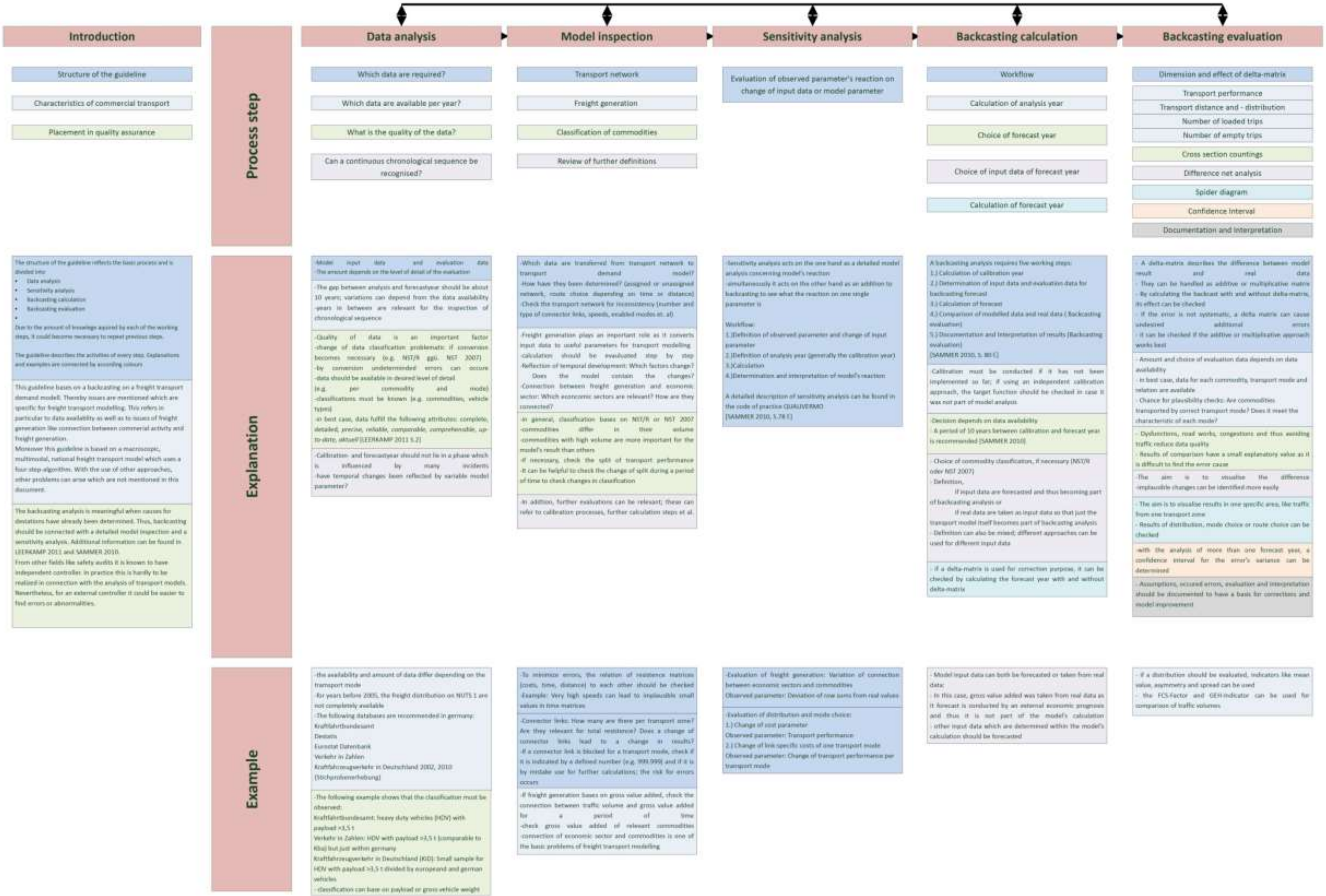
On basis of the previously described experiences, a guideline was developed which should avoid the arisen problems and which should make the backcasting method a useful and valuable method of quality assurance.
Using the backcasting method has revealed that it cannot be seen as an independent instrument of quality assurance. For this reason, it seems reasonable to combine this approach with other methods of quality assurance in order to handle all aspects that exceed the backcasting method. In a first step, the amount and the quality of the data and its values must be checked. As a reference point, the criteria defined by Leerkamp (2011) can be used. In addition, the chronological sequence of the data should be evaluated to determine a backcasting year. The data analysis should occur in close connection to a model inspection to make sure that input and output data correlate with the empiric data concerning classification or level of detail. It has been pointed out that in most cases the backcasting method cannot identify the reason for deviations from empiric data. Thus, it is recommended to use additional methods as well. The sensitivity analysis is one possibility, for instance, where just one parameter is changed for a defined value to see the model's reaction, which leads to an easy insight into the model's behaviour. By combining all the mentioned methods a process of model evaluation can be established, which connects the strength of each method while compensating the weaknesses. Thus, a quality assurance process will be established, which analyses a number of criteria, from data quality to forecast capability. The following figure displays the process of model evaluation.

Figure 3: Process of model evaluation



The process should not be seen as an inflexible process. It is rather meaningful to repeat single methods if new information from following steps arose.

The following page shows a guideline, which is the result of a detailed backcasting analysis. It illustrates the described process and points out the important process steps (first row) by keywords and central questions. The second row (explanation) presents detailed descriptions for each keyword. They are connected by the corresponding colour. Same applies to the third row (examples), which completes the guideline by providing potential problems/challenges and practical notes.



Introduction
Data analysis
Model inspection
Sensitivity analysis
Backcasting calculation
Backcasting evaluation
Process step
Explanation
Example
Structure of the guideline
Characteristics of commercial transport
Placement in quality assurance
Which data are required?
Which data are available per year?
What is the quality of the data?
Can a continuous chronological sequence be recognized?
Transport network
Freight generation
Classification of commodities
Review of further definitions
Evaluation of observed parameter's reaction on change of input data or model parameter
Workflow
Calculation of analysis year
Choice of forecast year
Choice of input data of forecast year
Calculation of forecast year
Dimension and effect of delta-matrix
Transport performance
Transport distance and - distribution
Number of loaded trips
Number of empty trips
Cross section countings
Difference net analysis
Spider diagram
Confidence interval
Documentation and interpretation

6. Discussion

Within this work, a guideline was elaborated that integrates the backcasting analysis in a process of quality assurance. In addition to the working steps of a backcasting process, each of the steps are explained and completed by examples or advices.

There are also only few field reports on backcasting (see e.g. Gunn et al., 2006; Cambridge Systematics, 2010; Hernandez, 2012). However, the current state of existing literature already consists short guidelines on the working steps of backcasting (see e.g. Sammer, 2010). Compared to the guideline elaborated within this work, these are just basic steps without support concerning model's preparation, data collection or other preparing steps. The same applies to approaches for the work with backcasting results and its interpretation. Thus, this work led to a progress concerning a comprehensive and detailed guideline for backcasting of transportation models.

The work on the guideline was based on a conducted backcasting. While lots of references describe backcasting as a helpful and valuable approach for quality assurance (Gunn, 2006), the arisen problems of data availability and quality generates the question, if backcasting can fulfil its expectations. The most important results and findings have been summarized in the guideline. These advices can help to assess whether backcasting can bring additional information concerning model quality or not. Even if some evaluation data are not available, there can be some alternatives which provide comparable or additional information. Thus, we recommend having a deep insight into the preparing steps of data analysis, model inspection and sensitivity analysis to decide whether backcasting should be conducted.

Although, the guideline has been elaborated with accuracy and with respect to lots of details, it has to be considered, that the introduced guideline has been developed with the use of a commodity based four step freight transport model. In case of other model types, different use cases could appear which are not mentioned by now.

Furthermore, the guideline is based on a single examination. When working with other models and dealing with other constellations of analysis and backcasting years, the arising problems and optimal working steps may differ to some degree from the described ones. Nevertheless, the guideline works for most state-of-the-practise models.

Another important fact is that the results of the network assignment were not considered within this work. Similar to other generalized data, traffic volumes of single tracks have just a small explanatory power so that it is expected to bring only a small amount of additional knowledge. Nevertheless, this could be analysed within further studies.

7. Conclusion

The analysis of existing literature on backcasting has shown that there are currently only a few studies and reports dealing with either theoretical approaches of how to conduct a backcasting or practical experiences on model evaluation based on backcasting. This is a significant problem due to increasing freight transport, relating policy issues and the increasing use of freight transport demand models in order to assess related policy measures. Thus, ensuring quality and accuracy of the used models remains an important issue and challenging task. The project "QUALIVERMO" created, to our state of knowledge, one of the first codes of practice in this area and, thus, provided a basis for the present work.

The reviewed literature assesses backcasting in many cases as an excellent and high quality instrument to evaluate model quality and forecast capability. The practical application, however, has revealed that serious problems may occur. Important issues are data availability, their quality and its chronological sequence. As the whole process is based on a good data set, the data analysis becomes the first important step when conducting backcasting. A critical aspect of backdated data is the change of commodity classification. This applies in particular to the European context in 2007 (NST-R to NST2007) but also to changes of classification in general. In that case, this leads to the need of additional transformations and generates additional sources of errors.

Concerning the input data another challenge occurs: how to define the extent of the observed model? On the one hand, the forecast of the input model can be seen as a part of the model so that input data have to be forecasted for the backcasting analysis. On the other hand, if the input data are taken from an external source it can be seen as a separate, independent model with no need of observation.

As main result of the findings and experiences, a guideline was developed, which combines three different approaches of quality assurance: data analysis, sensitivity analysis and backcasting analysis. Combining them in connection with a detailed model observation enables the user to utilize the strength of each method. Thus, a quality assurance process will be established, which ensures a broad model evaluation.

However, the current status of the guideline is only based on a single examination of backcasting. It was conducted using a four step freight transport demand model. Thus, the guideline should be completed and optimized by means of further studies working with other modelling approaches or other input data.

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