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Conceptual Aspects for a Valuation- and Optimization- System for Transportation Processes with Special Regard on Air-bound Traffic

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Abstract

Based on the trend of growing role for airbound traffic on the one hand and the growing need for efficient and economic transportation, this paper gives an intermodal approach to describe the whole transportation task " from door to door". To do this, the concept of the "transport chain" is introduced and formalized. On the base of this overall-model of the system, the optimization objectives are formulated with special respect on the local views of the different stakeholders that offer the different services along the transport chain. Additionally, the transport chain concept is used to couple existing models of the transportation domain by modularization into independent transportation steps and an interface between these steps that abstracts from the steps' implementation by focusing on guarantees for the service offered, only.

1. The Motivation: Growing Relevance of Air-Bound Traffic

This paper is motivated by the growing role of airbound transportation on the one hand and the growing differentiation and flexibility concerning the choices the end-users are offered for a certain transportation task on the other hand. To describe the current situation, four observations can be made:

1. A growing use of the airplane even for short distances can be observed. The developers optimize the aircrafts by a reduction of fuel consume and an increase in capacity to reduce costs. In consequence, flying becomes more and more usual even for short distance transportation.
2. To evaluate costs, travelling time and the environmental impact of a travel, there are lots of approaches to compare the alternatives for transportation to each other [3]. Criteria for those comparisons are the costs on the one hand and the environmental aspects and effects of the use on the other. The results are the well known indicators for environmental impact. Those data allow calculating the corresponding cumulative costs and environmental impacts for each travel.
3. Especially with focus on air-bound travelling, the influence of the flight itself on the indicators mentioned above decreases more and more, whereas additional factors that had been neglected so far, such as how to go to the airport, the time needed for check-in and security checks, etc. become of increasing relevance.
4. From the point of view of the stakeholders operating air transportation, the air transportation system has to generate financial profit first, but seems to be intransparent and hardly prognostable because of its complexity and flexibility.

Therefore, this paper approaches the problem by a top-down-concept trying to integrate

- the complete transportation chain from "door to door",
- evaluations concerning travelling time, costs, and environmental impact,
- the different views of the participating stakeholders.

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The approach is model based to profit from knowledge represented by already existing models and intends to offer a framework for easy experimentation with new technical developments given by variations of the corresponding model components. Main intention, however, is the ability to optimize the transportation system by easily switching between the given alternatives for every step in the transportation chain, even by variation the means of transportation. The paper will show that three topics are of specific relevance and interest in this context:

- valid composition of the transport chain from a given set of model components
- finding and evaluation of optimization criteria as well as for the different levels of abstraction as for the individual stakeholders
- specification of the intermodal nodes, where the means of transport is changed.

2. The Context: The System "Air Transportation"

According to the objective of an integrated valuation and optimization of transportation processes, an over-all approach concerning the means of transportation and the combination of passenger and freight traffic seems to be adequate. Therefore the following objects (in the sense of an object oriented model design) should be represented:

- passengers
- freight as containers and individual packages

For both types the transport chain has to be modelled not only as a connection from airport to airport but as a mixed mode transport chain starting at an arbitrary starting point to any other geographical position. This view on the system implies a multilevel and multi-scale transportation graph as basic data structure to work with. First, efficiency factor based approaches have been developed in the past to build up such comparable modelling method to assess intermodal transportation chains. Those already existing approaches that implement such scenarios seem not to satisfy the demands concerning the modelling concept intended by this paper; their "global" view seems not enough. To optimize the system, the different views of the stakeholders (, such as airlines, airports, service providers at the airport, etc.,) participating are of major interest. Their "local" views have to be considered, a fact that leads to a differentiation of the global view at least on the level of optimization criteria and, in general, to a multicriterial optimization task to be solved. Exactly this difference to a point-to-point-transportation on global level, i.e. from the point of view of the passenger (or the freight!) complicates the approach and is worth to be discussed in the next section as a detailed problem specification.

3. The Problems: Specification

3.1 Functional Decentralization versus Global Optimization

One of the most relevant trends in the field of transportation is to outsource well defined sub-tasks to specialized service-providers with the intention to reduce costs and to make it possible for each of the stakeholders to focus and concentrate on their own business zone. This might be a good strategy on operational, microeconomic level, but it implies a fundamental problem concerning the optimization of the business processes as well as the transportation itself: In the terms of systems theory, the global transportation system is divided in relatively autonomous subsystems with their own management component and own objectives. These sub-systems have to cooperate concerning the common objective to carry out the transportation task, but beside of the procedural level at the interfaces between the decentralized service providers, they will have quite different business objectives that guide their internal behavior.

In consequence, optimization the transportation task on global level will not necessarily lead to optimal results for each of the participating stakeholders representing the sub-systems and operating the global transport. This observation is valid for the inverse direction of argumentation, too: optimal design of the processes within the subsystems does not lead necessarily to optimal results on the level of cooperation of these subsystems. So far, the intention to optimize the system on global level would demand for a central management level on global level as well, a postulation that conflicts with the current trend for decentralizing and outsourcing. To heal this deficit, the stakeholders might be given some incentives to operate in the sense of a global optimum, but to specify the value of those incentives a comparative model should exist. By these deliberations, three main tasks are worked out in respect to modeling the transportation chain:

1. There should be differentiated optimization criteria for each stakeholder mirroring the local situations in the stakeholders' subsystems.
2. These local criteria should be treated either by a merging function and combined to a common indicator for process-, i.e. transportation-quality or be processed by the means of multicriteriel optimization theory.
3. If a solution on this level fails, game theoretical aspects might be applied to find a balanced solution by modeling the dynamic process of cooperation and subsequent evaluation. In this situation, there is a strong need for criteria how to adapt the local process execution in accordance to the experiences made in former situations.

All these alternatives demand for a properly elaborated concept for indicators, objective functions and evaluation, a topic that is treated in some more detail in the following section.

3.2 Levels of Objectives

To structure the optimization part, a precise description of the different dimensions for evaluation of model results is necessary. There are three dimensions readily identifiable and discussed e.g. in [4]:

- The economical dimension: What does it cost?
- The ecological dimension: What are the ecological impacts?
- The dimension of transportation time needed.

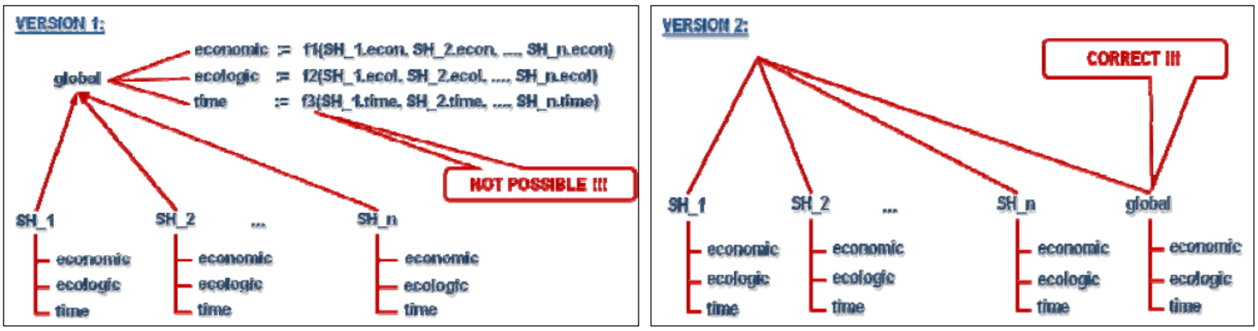

Fig. 1: The relation between the global valuation and the valuations for the stakeholders.

However, with respect to the logistical implementation of the transport process in the real world, an additional dimension has to be taken into account:

- The actors dimension: Every stakeholder has to be treated separately and characterized by at least one indicator value for process quality. In addition, there must be one value for the rating of the system on global level.

As figure 1 will depict, the global valuation may not be derived by the valuation for the stakeholders but has to be calculated separately. Time consume, costs, and ecological impact are independent dimensions for each of the stakeholders and may not be summarized.

4. The Formalization: A Multi-Modal and Multi-Level Approach

4.1 The Formal Problem and its Solution

In this section, a formal description of the transportation system will be provided. The specification is basically based on a grammar for the real world objects such as "transportation job", "transport", "transport chain", the surrounding terms to make the grammar complete shall not be listed in the context of this paper because of the page limit.

```
transportation_job ::=        JOB job_identifier                        # job_identification
                              "("    start_position       ","           # geographical position or node number
                                     end_position         ","           # geographical position or node number
                                     cargo_list           ","           # specification of cargo
                                     time_restraint                     # time interval
                              ")"

cargo_list         ::=        cargo                                     # only one type of cargo
                        |     cargo AND cargo                           # mixed transport (persons and freight)
                        |     EMPTY                                     # no cargo at all (needed for "transport")

cargo              ::=        PERSONS  "(" integer ")"                  # number of persons
                        |     FREIGHT  "(" integer ")"                  # weight of the freight

time_restraint     ::=  "["   time     ","                              # earliest_start_time in time-format
                              time     "]"                              # latest_arrival_time in time-format

transport_chain    ::=        transport CONCAT transport_chain          # concatenated transports
                        |     epsilon                                   # end symbol for the list

transport          ::=        TRANSPORT transport_identifier            # specifies one link of the
                              "("    means_of_transport  ","            # transport chain
                                     start_position      ","            # geographical position or node number
                                     end_position        ","            # geographical position or node number
                                     cargo_list          ","            # list format for mixed cargo transports
                                     start_time          ","            # in time-format
                                     arrival_time        ","            # in time-format
                                     evaluation_criteria_list           # vector with vauation criterias
                              ")"
```

```
means_of_transport::=      AIR    "(" air_identifier   ")"   # type and identifier of the carrier
                      |    TRAIN  "(" train_identifier ")"   # type and identifier of the carrier
                      |    TRUCK  "(" truck_identifier ")"   # type and identifier of the carrier
                      |    BUS    "(" bus_identifier   ")"   # type and identifier of the carrier
                      |    CAR    "(" car_identifier   ")"   # type and identifier of the carrier
                      |    ....                              # analoguously for additional carriers

mobility_net      ::=      <... bipartite, directed graph ...>

intermodal_nodes  ::=      < see description in separate paper!>
```

This formalization allows formulating the general task to be solved by the valuation and optimization system very precise: In consequence of the formal description, the formal problem is nothing else but a mapping between a set of transportation jobs to a transport chain that will consist of several transport steps executed by different means of transport under the management of different stakeholders on the given infrastructure, the transportation net.

To generate a valid solution for the mapping and for validating and optimization, the following basic algorithmic steps are identified:

- **Step 1: Find alternatives for a valid transportation chain!**
  This will be possible by finding valid words derived by the grammar introduced before.
- **Step 2: Find an optimal routing for the separate transports in the transport chain!**
  There are elaborated algorithms, e.g. in [6], to solve this task, the challenge lies in an adequate balance for the costs in accordance to the different objective criteria for the multicriterial problem as explained in section 3.2.
- **Step 3: Evaluate the alternative!**
  Again, a multi-level, multi-dimension valuation has to be executed. This step will be easy because it simply calculates the different indicator values. The subsequent step will be:
- **Step 4: Make a ranking for the alternatives found!**
  In this step, the comparison takes place. It is open so far whether the ranking is made automatically or by the aid of an experienced expert, but independently of this procedural decision, it must be supported by graphical methods to visualize the decision space and/or by the theory of partial ordered sets ([1],[8]) to facilitate the decision itself.
- **Step 5: Optimize the current solution!**
  For an automated optimization, elaborated algorithms exist (e.g. in [7]). Again it will be crucial to find adequate optimization criteria that do not only valuate an alternative in a descriptive manner but also allow deriving probable better alternatives using the criteria in a constructive manner.
- **Step 6: Increase the efficiency of the search!**
  Obviously, the algorithm sketched so far, has to work on a very large search space. To restrict the search, heuristic restrictions might be imposed on several stages. A rule-based approach seems to be promising and should be integrated at least in the steps 1 and 2.

4.2 Technical Consequences

With the formalisation in form of a grammar generating alternative transport chains, the top-level of the evaluation and optimization system is fixed. However, to realize and to implement the system there are three issues that rest:

The first one is the combination of different, already existing models to a common transport chain on technical, i.e. software-technological level. The problem is well known as coupling of models, and several approaches can be found in the literature ([5],[10]). The solutions these approaches propose lead to a central control unit that communicates with the models to couple. On technical level, this seems to be a good solution, but it is very elaborate as well.

For the context of transportation, the authors suggest a more pragmatic solution: Again, the construct of the transport chain will help in this situation: This chain bases on an interface specified with respect to the logical level but not to the technical one. Therefore, the interface will deal with persons and freights to transport under certain restrictions on the logical level of the transportation job, but not with technical details about the model interface. The aim of the project is, to define such a transportation job by additional values for scale, accuracy, validity, etc. in the sense of warranties the stakeholder assures for his service and therewith for the relating link in the chain. Doing so, the links can be linked on this logical level under abstraction from the technical one.

The organisational problem will be, to get the information from the stakeholders and/or the developers of the sub models on this level, but on the other hand, without these data any further engagement to improve the transportation system on the whole would be senseless.

Under this logical point of view the intermodal nodes (i.e. the nodes where the means of transport changes) become of eminent importance. The strategies for loading and unloading at these positions are the key parameters for the whole system. A separate article shows the potential of these intermodal nodes and the corresponding parameter set in some more detail [2]. For the door to door problem in transportation, these links deserve lots of attention.

4.3 Consequences for Valuation

Obviously the valuation criteria used will attract highest interest, too. As explained in 3.2, the optimization problem is not only multi-criterial, but it additionally holds multi-dimensional aspects by the set of stakeholders treated. In the current state of the project we just can mention this issue and refer to several methods for ranking multi-dimensional sets but we cannot offer a proved solution for the transportation context. Main objective will be to develop a measure that not only allows a sophisticated ranking but also provides a continuous scale for optimization purposes. By current assessment, this will be the most crucial problem to solve for the overall valuation- and optimization system.

4.4 Dimensions of the Problem

Figure 2 provides a comprehensive view on the project: On the top-level the geographical situation is sketched by the transportation net or in a more elevated term, the mobility graph. It holds nodes and links for all the means of transport supported and allows a routing independently of a pre-specified means of transport on the one hand and of a certain carrier (or stakeholder) on the other.

In the center of the figure we can find the transport chain consisting of transport steps. Every transport step has to be mapped to a certain route in the mobility graph under restriction of the services provides by certain stakeholders. This mapping represents the logical aspects of the transport. To model and simulate a transport step, a corresponding model description and runtime system should be available. This aspect is depicted by the mapping of the transport step to a model component arranged along an axis that describes the scale of the models. There might be very simple static (may be statistical) model components, components using next-event-simulation concepts, differential equation models down to very elaborated 3D models using finite element descriptions. The coupling of these models can be realized on the technical level as well as on the logical level as described before. Around this basic architectural concept that shows the implementation for calculating respectively simulating one given transport alternative, the basic algorithmical steps explained in 4.1 for evaluating and optimizing the alternatives have to be considered.

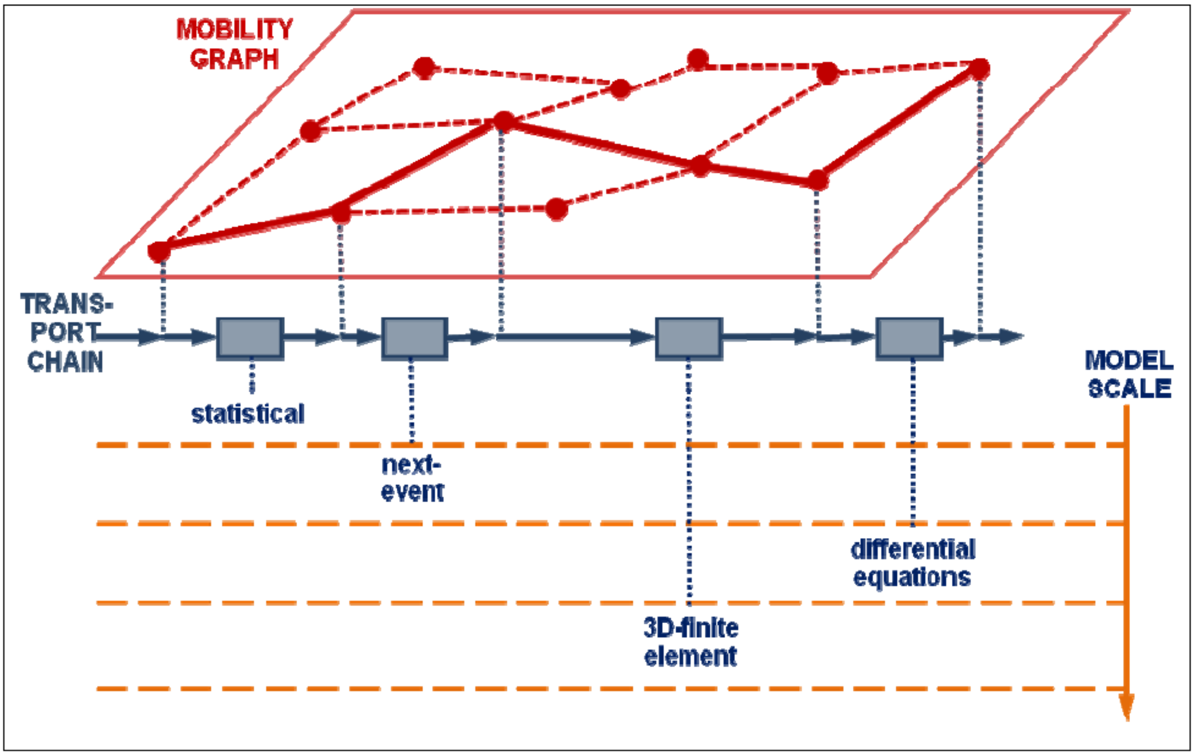

Fig. 2: a comprehensive view on the project

5. Conclusion: Demanding Tasks for the Further Course of the Project

The project described is in its initial phase that is why there are no running simulations and demonstrations so far. However, the intention of this paper is not to present simulation results but to give a comprehensive overview over the problem and the methodological approach to its solution. Similar situations will be recognized in divers application areas that are characterized by

- multi-modality
  in the project as a change of the means of transport used to provide a certain transportation service; in general as a change in the paradigm of an arbitrary service provided. What we have learned is the importance of the proper specification of the intermodal nodes as the transfer stations between (at least) two different modes of service. In short, there are various strategies to reload the service tasks, and in general the observation can be proofed that the efficiency of the system increases with increasing capability to buffer tasks at these stations and subject the redistribution to a highly sophisticated strategy. Because of their importance, these strategies should be specified and documented carefully!
- multi-scale
  in the project as a coupling of models with different scales concerning time resolution, granularity in space, and granularity in the view on the transportation task; in general every difference in modelling paradigm in combination with coupled models or model components. Concerning the multi scale problem, the focus has ti lie not only on the level of a technical solution to make an interaction and a data exchange between the components possible but also on the semantical level of the

interface. Especially the preconditions for the different modelling paradigms used have to be kept and assured by transformation functions transforming the values of the model quantities from the one scale to the other (e.g. population dynamics by differential equations on statistical level to individual-based models [9]).

- multi-criterial
  Concerning the optimization task the paper specifies and discusses the situation of a multi-criterialobjective function as known from many other investigations but escalates the evaluation problem by introducing an additional differentiation in accordance to the stakeholders enlisted. It is worth to elaborate a general specification of such a situation because the different views and objectives open a completely new dimension that demands a special consideration in the optimization algorithms used. It is obvious that the situation explained here in the context of air-bound transportation appears in many other application areas and deserves high attention for the optimization problem. It tightens the multi-criterial situation by the simple fact that the optimal solution for each of the stakeholders does not necessarily lead to an optimal solution concerning the overall system. In this context, the paper tries to offer a proper problem description hoping to initiate an accordant discussion in the optimization community.

Beside of these aspects, the paper proposes a problem-centred interface between the model components and simulators coupled together by using the original level of problem as the constructive coupling interface: the transportation job itself. By attributing each job with certain warranties concerning tolerance and time, this high level interface offers a practicable level for letting the very different components interact with each other and for optimization the system behaviour on top level.

References

[1] Brüggemann, R.: Workshop on Ranking Methods in: Hryniewicz, O.; Studzinski, J.; Szediw, A. (Eds.): EnviroInfo Warshaw 2007 – Environmental Informatics and Systems Research, Vol. 2, Aachen 2007, pp. 169-226

[2] Göbel, J., Wittmann, J., Möller, D.P.F., Schroer, B.: Modeling a Generalized Intermodal Node for Mesoscopic Traffic Simulation, in: Gauthier, J. (Ed.): Proceedings of the Huntsville Simulation Conference, SCS Publ., San Diego 2007, pp. 177-185

[3] V. Gollnick: “Benchmark Studies of the Efficiency of Intermodal Transportation” (In German) PhD Thesis, TU Munich, 2004

[4] V. Gollnick, E. Stumpf, J.Szodruch, W. Grimme: “Air Transport beyond 2020”, AirTN European Forum Green Air Transport, Bonn, October 31st 2007

[5] High Level Architecture (HLA), IEEE-Standard 1516, 1516-2000 IEEE standard for modeling and simulation (M&S) high level architecture (HLA) – framework and rules, http://ieee.org

[6] Russel, Stuart; Norvig, Peter: Künstliche Intelligenz – Ein moderner Ansatz (2. Aufl.), München 2004, Kap. 3.2.2, S. 98 ff

[7] Schwefel, Hans-Paul: Evolution and Optimum Seeking, New York, 1995

[8] http://de.wikipedia.org/wiki/Partielle_Ordnung (01.04.08)

[9] Wittmann, J.: Experimental Design for Agent-Based Modeling Approaches, in: Troch, I., Breitenecker, F. (Eds): Proceedings of 5th Vienna Symposium on Mathematical Modelling, Argesim-Verlag, Vienna 2006, ISBN 3-901608-30-3, Section on Modeling of Environmental Systems pp. 2.1-2.7

[10] Wittmann, J.: Automatische Modelltransformation zwischen unterschiedlichen Simulationssystemen – Erfahrungen aus dem Projekt SACOM, in: Panreck, K.; Dörrscheidt, F. (Hrsg.) : Simulationstechnik - 15.Symposium in Paderborn, September 2001, SCS European Publishing House, Ghent 2001, S.101-106