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# The Meaning and Importance of True Intermodal Route Planning in the Context of the Physical Internet

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***Abstract:*** *Within this paper, we present a comparison between "presumed" intermodal route planning and true intermodal route planning. We will show that intermodal route planning does not necessarily mean that the obtained route is intermodal but that it is sufficient that under other circumstances (e.g. different traffic situation) an intermodal route would have been suggested. Furthermore, we will point up that the tools for true intermodal route planning are already developed and basically a mind change needs to be achieved. We will also highlight how true intermodal route planning is an essential prerequisite for synchromodality and therefore for the application of the Physical Internet.*

***Keywords:*** *Intermodal Route Planning, Synchromodality, Applications of Intermodal Route Planning, Transportation Network Design, Service Network Design, Operational Decisions*

## 1 Introduction

In recent years, the computational support in planning supply chain processes significantly increased. E.g., a multitude of computer aided planning tools for dispatchers emerged. This is, on the one hand, very welcome as the complexity of the planning tasks steadily increases meaning that human capability of overlooking the whole process reaches its limits. On the other hand, this development bears some pitfalls. E.g., even if a computer aided system is designed in such a way that the final decision (and therefore quality assurance) will be taken by a human, the decision process will be heavily guided by the decision support tool. If the tool itself has conceptional flaws it is therefore very likely that these are adopted during the final decision process. It is therefore essential that (at least) the very fundamental parts of such a decision support tool are reliable and apply the very last state of knowledge. Although the basis of the concept of the Physical Internet (PI) is rather widespread over many disciplines, one essential building block is (sustainable) transportation and therefore plain routing, i.e., path finding in a transportation network. Due to the nature of the PI this transportation network has to be multimodal as otherwise the concept of synchromodality would not be possible (Prandtstetter et al., 2016; Pfoser et al., 2017; Putz and Prandtstetter, 2015).

With respect to transportation, PI aims at providing synchromodal transportation chains. Synchromodality can hereby be seen as the logical evolution of intermodality towards real-time capability and ad-hoc re-routing (Prandtstetter et al., 2016; Putz and Prandtstetter, 2015). That is, contrary to a classical planning approach, synchromodality builds upon the possibility to re-plan transportation chains "on the fly" based on current traffic and/or order situations and incidents. For this online re-planning process, it is essential to have *true* intermodal route planning tools available. With *true* intermodal route planning we refer to a planning process which consists of three building blocks:

- **indicating optional modes of transportation vs. premature mode choice**

  In our understanding (and contrary to state-of-the-art planning tools), the actual mode choice should be a well-educated decision, meaning that the person in charge of transport planning is not selecting the main outline of the supply chain (e.g. truck-train-truck). This person only defines which modes of transportation are theoretically possible (e.g. truck, train, ship, but not plane).

- **automatic vs. predefined selection of transshipment points**

  Analogously to the selection of modes of transportation, the person in charge of transport planning should not preselect the points of transshipment (e.g., port of X). In best case, this person should be able to specify some preferences (e.g., at port of X we get a discount of 10%, or at port of Y we had bad experiences).

- **generation of a set of promising route options**

  Based on the two inputs described above, the route planning tool has to generate not only one optimal route but a set of (almost) equally good routes. E.g., one route might be faster while the other one might be cheaper. The final decision can then be left to the dispatcher. Please be aware, that the best route might be unimodal. Nevertheless, the planning process is intermodal.

It is, however, quite interesting with respect to (true) intermodal route planning that strong parallels between freight transportation and passenger transportation exist (cf. Prandtstetter et al., 2018). Even more, we claim that the same methods used for passenger transportation can be directly applied for freight transportation. However, we also claim that the state-of-the-art approaches are not capable of providing true intermodality.

The remainder of the paper is organized as follows: First, we give a definition of true intermodality followed by a short presentation of algorithmic solution approaches in Section 3. Section 4 will then show application areas and the therewith related impacts. Conclusions will end up the paper.

## 2 Definition of True Intermodality

Basically, there are a lot of existing interpretations when talking about multimodal, comodal or intermodal routes. This “Babylonian language confusion” is partially based on the fact, that there are severe differences in wording with respect to passenger and freight transportation. On the other hand, this confusion is based on the similarity in meaning (Prandtstetter et al, 2016). For example, for passenger transportation an intermodal route involves more than one (i.e. at least two) different modes of transportation (MOTs) while this characteristic (more than two MOTs) refers to multimodal routes in freight transportation. Intermodal freight routes are, however, multimodal freight routes with the additional characteristic that only one loading unit (e.g. container) is utilized throughout the whole transport. For the sake of readability, we will use the wording intermodal throughout the rest of this paper in its original meaning for passenger transportation. This meaning especially applies with respect to applications in the context of the PI since for the underlying concept of synchromodality the requirement of the same loading unit must be softened (cf. Prandtstetter et al., 2016; Putz and Prandtstetter, 2015).

When talking about true intermodality, we have to discuss the difference between

- the input for route planning,
- the actual route planning process (including the obtained result), and
- the actual traveled route.

### 2.1 Input for Intermodal Route Planning

When having a closer look on state-of-the-art route planning processes, we easily see that a common input format is as follows:

- **the origin and destination of the route**

  Obviously, when planning a trip, it is necessary to specify at which location the trip should start and at which location the trip should end.

- **the departure time or arrival time of the route**

  Modern route planning services incorporate not only plain transport network data (e.g. roads, or train schedules) but also rely on some real-time (or estimated) traffic data (e.g. current travel times, or delays) during route computation. Obviously, it is necessary to have some information about the departure and/or arrival time since otherwise an estimation would not be possible. There are, however, some services which lack this type of functionality (e.g. some route planning services for hiking or other application areas where either the data source is not accessible or no meaningful data exists).

- **the involved modes of transportation**

  Since intermodal route planning is addressed, it is necessary that more than one MOT is specified to be used along the planned route. To the best of our knowledge, state-of-the-art approaches for intermodal routing do not allow to freely select different MOTs but they have to select some (typical) combinations like "bike-and-ride" or "park-and-ride". In some situations, public transport routing is also referred to as intermodal since walking and some public transport vehicles are involved. However, when arguing like that, almost all routes are intermodal since (at least for passenger transportation) all routes start and end with walking. The same argumentation applies to freight transportation where, even if only truck transportation is involved, goods have to be loaded/unloaded into/from the trucks.

- **the intermediate transition points**

  For some services, especially in combination with "park-and-ride" features, it is possible (or necessary) to specify a specific transition station. Although this might be handy when your car is already parked at such a station and you want to plan your return journey, it is rather unhandy to specify a transition station, when you have no further information (e.g. time schedule of public transportation, or amount of available car parking slots). Obviously, the same applies in freight transportation, where the intermediate points are typically hubs used for changing from one mode of transportation to another one. Why do shippers in e.g. Austria have to select whether a container to USA have to be transported via Hamburg, Germany, or Rotterdam, The Netherlands? In fact, this decision is crucial for the performance of the trip (e.g. costs, or travel time) but cannot be made if not enough information is available.

Although this parts of input are common and to some extent are obvious, we demand that for future services, the input has to be changed to the following input:

- **the origin and destination**

  With respect to this input, we see no meaning in changing something here.

- **the departure or arrival time of the route**

  Again, we see no further meaning in changing something here. If, at all, we suggest that this option is always available (even in cases where the impacts of changing the departure/arrival time might be neglectable).

- **the involved modes of transportation**

  Here, we propose that users are able to freely specify the desired MOTs. A very attractive design is provided by the journey planner of Travel York (2018). Here, the user can

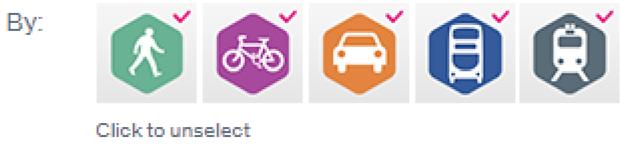


*Figure 1 MOTs selection as implemented by Travel York (2018).*

arbitrarily select a set of possible MOTs, see also Figure 1. (Unfortunately, the route planning itself is then unimodal, meaning that for each selected MOT one route using just this MOT is generated.)

- **the intermediate transition points**

  Instead of specifying a fixed transition point, we suggest that it is possible to specify the location of e.g. the car or bike (which might be at home or work or some other arbitrarily chosen position). One could think further that in addition a set of possible transition points is selected by e.g. stating that a park-and-ride facility from company A is ok but one from company B is not (e.g. since a monthly parking ticket for company A is already paid). Obviously, the same is true for transition points in freight transportation. Some hubs might be preferred due to special agreements or some legal frameworks. It is, however, necessary to think about the proper user (or data) interface.

As can be seen, the differences between the state-of-the-art and proposed input are not too large. At the same time, as will be further explained in the next sessions, these differences build the basis for a flexible route planning.

## 2.2 The Intermodal Route Planning Process

After having the input request, the next step is to plan the actual route. Here, again, differences can be observed between the common available state-of-the-art services and the in our view necessary approach:

- **integration of selected modes of transportation**

  There are two common approaches for route planning: The first one, as applied by Travel York (2018), is to let the user pre-select possible modes of transportation but do no intermodal route planning. That is, even if a set of routes is provided each route incorporates only one mode of transportation. In some cases, and we refer to the well-known Google Maps route planner for an example, it is only possible to select one MOT. Obviously, the routes are incorporating just this one MOT.

  The second state-of-the-art approach is to incorporate *all* selected MOTs into one route. If this approach is applied, the user interface normally restricts the number of freely selectable MOTs or limits the selection even to pre-defined clusters, e.g. park-and-ride. Unfortunately, the results obtained using this approach can be rather poor. E.g., an intermodal park-and-ride trip might then consist of taking the car for a few meters and then switch to public transportation, cf. also Prandtstetter et al. (2018) for examples.

  We propose, however, to allow flexibility: This means, that even though a user pre-selected a set of MOTs, this selection should be understood as "this is possible but not necessary". This means, that all or also just some of the pre-defined MOTs are incorporated in the resulting route. Even more, the resulting route might then comprise only one MOT. We therefore stress here, that intermodal route planning must not mean coming up with an intermodal route. It only means that intermodal options are compared against unimodal options. The best fitting route (independent of the number of MOTs involved) is then returned.

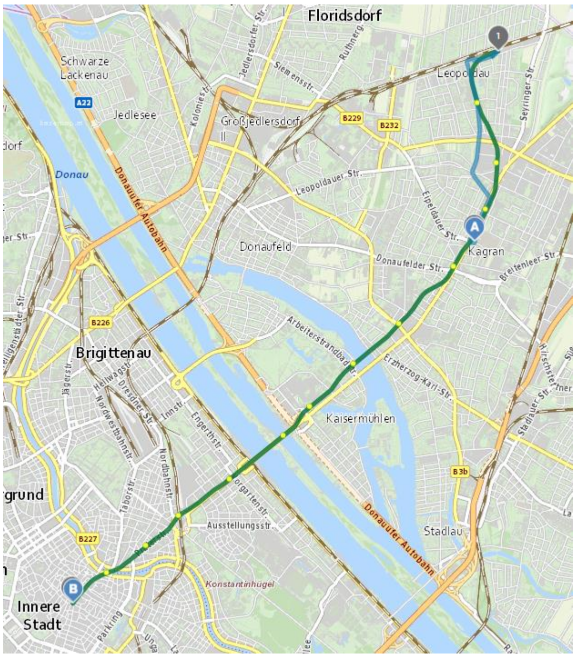


*Figure 2 A forced intermodal route with semi-fixed transition point.*

- **integration of transition points**

  The integration of transition points is strongly connected to the incorporation of different MOTs. In case the user interface (or logic of the route planner) requires that a transition point is pre-defined, it is obvious that state-of-the-art approaches take this transition point into account. At the same time, if a MOT combination is pre-defined (e.g. park-and-ride) it is obvious that a fitting transition point has to be selected. This might result in some weird routes as shown in Figure 2. Instead of suggesting a pure public transportation route, a bike-and-ride route is suggested from point A to point B due to user pre-selection. Unfortunately, the closest (or best suited) bike storage facility is in the opposite direction than the originally planned trip. This results in a public transportation route passing by the original departure location (which, by the way, is a public transportation station as well). The arising problem with this example is that beside the fact that intermodality is forced, also the transition point is forced to have specific characteristics (bike storage facility).

  We stress that future intermodal route planning service must be flexible enough to decide that among the possible transition points none is well located such that an intermodal route is not meaningful at all.

- **generation of alternatives**

  Some route planners provide the possibility to obtain route alternatives, that is, routes which differ either in departure time or directions. One good example is Google Maps (Google, 2018) which provides alternatives (especially for the road-bound MOTs car, bike, walking). Unfortunately, the alternatives are not always meaningful. E.g., as shown in Figure 3, one of the two alternatives for a trip from Vienna to Graz would take additional 40min of travel time (on a total travel time of approx. 2h). In addition, alternatives are limited to the very same MOT only.

  We suggest, however, that route alternatives should be computed based on the pre-defined set of possible MOTs. That is, that the alternatives provided might differ in the actual route (e.g. taking another road) but also in the MOTs incorporated.

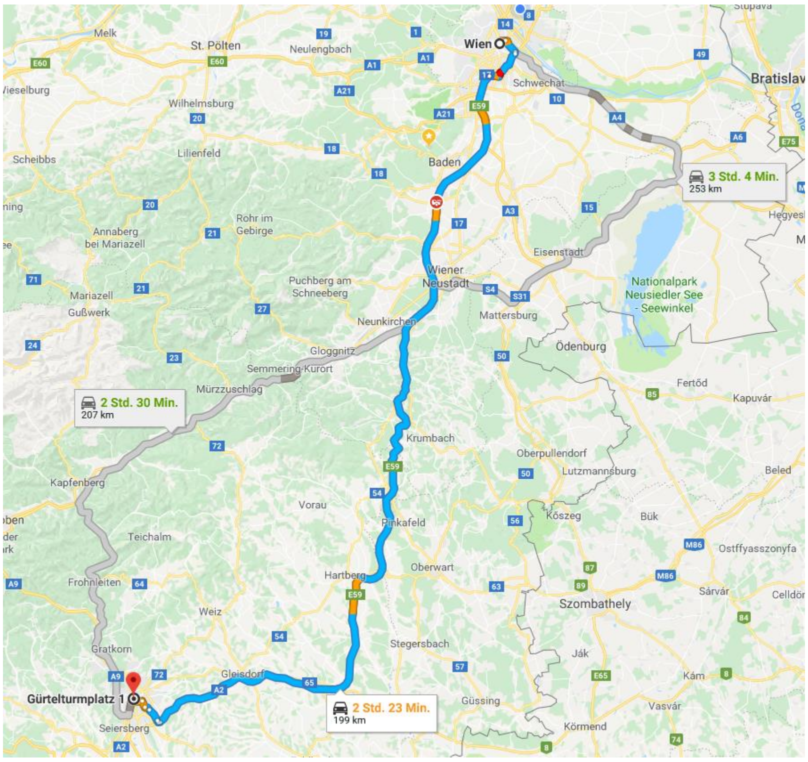


*Figure 3 Alternatives as provided by Google Maps (Google, 2018).*

### 2.3 The Intermodal Route Journey

The third step with respect to intermodal routing is the actual trip. Obviously, this is strongly dependent on the traveler and not so much dependent on the used journey planning device. We want, however, highlight that an intermodal route planning does not require that the trip itself is then intermodal too. There are various reasons which might be justified by some external parameters (e.g. availability of some resources) or by some internal parameters (e.g. custom).

However, and more important, especially in the context of the PI, we note that real-time re-planning of routes is one of the crucial factors of synchromodality. Therefore, it might happen that even though the route was perfectly planned to be intermodal some incidents (or additional orders) influence the re-planning such that a unimodal route is the then best option.

## 3 Algorithmic Solution Approaches

Within this section, we give a short overview on how intermodal route planning can be performed. Again, we highlight the differences of state-of-the-art route planners in comparison to our proposed true intermodal route planning approach.

### 3.1 Routing Network

Planning intermodal routes is not an easy task since compared to unimodal route planning a significant additional amount of input data has to be processed. This includes, among others, map data, time schedules, and availabilities of transition points (e.g. capacities in parking lots). Beside the fact that it is rather complex to have always up-to-date information, this multitude of data also brings in a multitude of options (e.g. instead of deciding only if to turn left or right at a crossing, it is for intermodal routing also an option the park the car and switch to walking, bike or public transport). Therefore, a common state-of-the-art approach is to partition the routing problem into different layers. Each of these layers is responsible for one MOT and connections between the layers are existing only at pre-defined locations (Partusch, 2018).

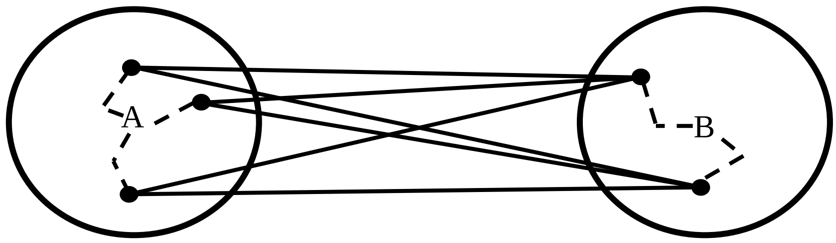


*Figure 4 Schematic graph of classical "intermodal" route planning.*

Depending on the flexibility of the system, these locations are either static or route request dependent. However, a classical (intermodal) routing request (for e.g. walking and public transport) is then answered by first finding all public transport stations in the proximity of the departure location. In addition, all public transportation in the proximity of the destination location are searched. Then, (unimodal) routes from all possible starting public transport stations to all possible ending public transport stations are calculated. Merged with the walks to/from the stations, the best route is chosen, cf. also Figure 4.

We propose, however, to employ the approach presented in (Prandtstetter et al., 2013) where a multi-layered network graph is constructed with each layer representing a MOT. Then, among all possible interchanging points a (virtual) connection is created (which can be even weighted according to some costs – e.g. time for transition). It is then very easy and straightforward to apply a classical shortest path algorithm like Dijkstra's algorithm (Dijkstra, 1959). Beside the fact, that this approach is rather flexible (e.g. the weights of the transition edges can be adjusted according to traveler preferences) this approach also guarantees to come up with the optimal, i.e. the best possible, route. In case, the best route is intermodal, the appropriate MOTs are involved. However, if the optimal route is unimodal this approach can also provide this unimodal route.

## 3.2 Providing Route Alternatives

When talking about finding alternatives, we have to admit that different approaches exist which cannot all be listed here. We have to highlight that even the definition of an alternative is not that easy and is a research field on its own (e.g. Dees, 2010).

One advantage of the modelling approach presented in (Prandtstetter et al., 2013) is that it is very easy to assign to each MOT an individual weighting factor. While the original optimization problem is to find the fastest route throughout the transportation network, the weighted optimization problem is to find a route which minimizes the weighted travel time.

We refer to Figure 5 for an example of the weighted route optimization problem. Here, we see a small graph representing the walking layer below the dashed line and the bike layer above the dashed line. Numbers indicate the travel time needed when traveling along the edges. Obviously, the fastest route to get from left to right is to first bike and then switch to walking (with a total travel time of 8). However, in case the biking layer is weighted by 2 (indicated in the Figure by *2), we obtain the fastest route by walking (travel time 10) since the travel time for pure biking changed to 18 and the travel time of the previously best route changed to a total travel time of 11. We refer to (Prandtstetter et al., 2018) for further examples.

The advantage of this approach is that personal preferences can be incorporated in the routing. For example, if a person is able to walk but prefers biking, then the (relative) weight for walking and bike should be accordingly adjusted. E.g., a weighting of a factor 2 as in the above example, indicates that one minute of travel time walking is perceived as two minutes taking the bike. Since appropriately setting these weights is rather complex, we suggest that the same route

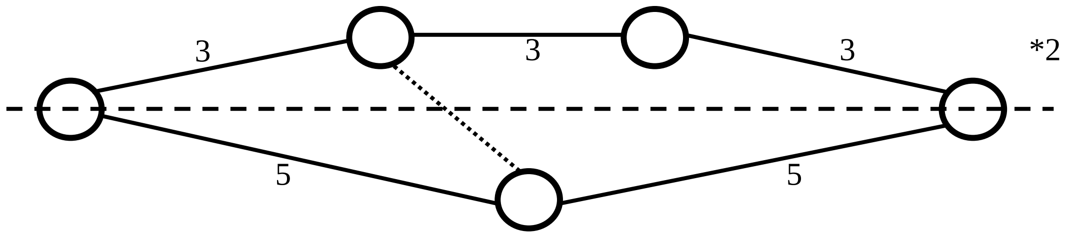


*Figure 5 Examplary graph with nodes above the dashed line representing the bike layer and graphs below the line representing the walking layer. Number given at the edges represent the actual travel time. The dotted line represents a possible transitions from walking to bike (or vice versa).*

request should be answered with different (rationally chosen) weightings such that a set of route alternatives is generated. This set is then presented to the user who has to decide which route is preferred.

One can go even one step further in that sense that not only optimization with respect to travel time is possible. Other optimization goals could be costs or environmental key performance indicators like CO2 emissions. Furthermore, weighted sums of these (and others) goals can be used as main objective function in finding the best route.

# 4 Application Areas in the Context of Freight Transportation

While the above-mentioned thoughts and results are mainly focusing on passenger transportation, we want to (once more) highlight that the route planning process for freight transportation is quite similar. In some situations, the parameters or inputs differ (e.g. transition points will most probably be selected on capacity, equipment and costs) but due to the flexibility of the presented approach the same planning algorithms can then be applied. While intermodal route planning is essential for passenger mobility of the future, this section focuses on other application areas arising mainly in freight transportation.

## 4.1 Promotion of sustainable modes of transportation

Having true intermodal route planning is of interest in application areas where sustainable modes of transportation (mainly train and inland navigation) shall be incorporated or even more be promoted. For that purpose, often, decision makers have few (if any) experiences meaning that they do not have the "gut feeling" whether it is a clever decision to switch to train/vessel or not. Therefore, handy and flexible planning tools incorporated in a smart designed decision support tool are necessary. Then, the decision maker can easily decide which option is (from an economical or ecological point of view) the best option. Important is, however, that true choice is only possible if (good) alternatives are presented. That means that forced intermodal routes which incorporate a lot of assumptions (e.g. pre-selection of MOTs, pre-selection of transition points, etc.) which most likely will not result in optimal (or at least good) alternatives will shake the decision maker's confidence in applicability of intermodal routes resulting in avoidance instead of joining the forces.

## 4.2 Transport Network and Service Network Design

Another important application area is transport network design and service network design. In these areas, the main goal is to plan the transportation network and services to be performed on that network. Obviously, the easiest (but also the worst with respect to sustainability) way would be to plan future transportation infrastructure only for road transportation (i.e., passenger cars and trucks). However, it turns out that (beside ecological sustainability) pure road transportation is also not sustainable with respect to economic goals. Therefore, an intermodal transport network is necessary. In addition, (intermodal) services on the network have to be planned. One major commonly applied step in planning these transportation and service networks is to simulate future utilization. Even though, if the future utilization would be intermodal due to manual planning, it is essential to have true intermodal route planning tools during that simulation phase.

### 4.3 Automation of Re-Planning

When talking about the PI, it is normally assumed that bundling and modal shifts are incorporated in freight transportation. Even more, it is anticipated that real-time re-plannings are incorporated. However, real-time re-planning can only be applied if automatic tools are available supporting modal switches as otherwise a re-planning would either take too much time or would not result in alternatives.

### 4.4 System-Aware Route Planning

The finally presented application area which is also closely related to the application within the PI, is the application in the system-aware context. While the PI context strongly focuses on the transportation process itself (real-time switching between MOTs, booking of PI service at PI hubs, etc.), the system-aware context focuses on the transportation system as a whole including all surroundings which are, among others, other traffic participants (freight and/or passengers), residents, communities, municipalities, schools, hospitals, etc. When aiming at a system optimum it is sometimes better to forego low-hanging fruits with respect to one individual trip and allow detours or delays such that other, maybe more important, services can be performed in superior quality. It is important that, however, these other services do not necessarily be related to transportation. Sometimes improving air quality for residents is more important than supplying a supermarket with the latest deliveries, just to mention one of thousands of examples. This includes, however, also a mind shift at the customers.

## 5 Conclusions

In this paper, we presented an overview on state-of-the-art “intermodal” routing approaches and suggested what to do in order to come up with *true* intermodal route planning. We refer by true intermodal route planning to trip planning that is neither forced to be intermodal nor constrained by assumptions which are made due to lack of knowledge or complexity. Further, we showed how to model the basic intermodal route planning problem such that well-known and efficient routing algorithms can be applied while at the same time flexibility (and therewith optimality) are introduced. We also showed that even though many of these considerations are originated in passenger transportation they are directly applicable in the freight transportation context. Even more, we showed that no changes are necessary for application in freight transportation.

We have, however, to conclude that even though methods are available and ready there is still a strong perception that intermodal route planning means that an intermodal route is performed. We have to stress that planning of routes and traveling are two independent steps. Even more, the result of the intermodal route planning might be a unimodal route. Still the process can be called intermodal route planning as long as an intermodal route could have been generated under different circumstances (e.g. different traffic situation) and intermodality is not forced at any time. We have the feeling that a lot of dissemination and persuasion work has to be done in order to come up with a true intermodal route planning process building the basis for synchromodality and therefore for the PI.

## 6 Acknowledgements

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