Modeling and Solving International Journey Planning Problems

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Abstract

The work presented in this paper aims to model and solve multi-criteria international itinerary planning problems. The emerging itinerary planning problems are defined on a multimodal time-dependent transportation network that consists of hierarchically interconnected international, interurban and urban transportation networks. The itinerary planning problems under study fall into two major categories: i) static, and ii) dynamic. The static refers to journey planning decisions at the pre-trip phase while the dynamic refers to the journey on-trip re-planning problem. An overall solution approach was developed for solving the proposed international itinerary planning problems. This approach involves a pre-processing stage in which a customized international sub-network is designed and stored for each pair of potential origin and destination countries of a trip request. In this context, addressing any trip request involves recalling just the corresponding customized sub-network instead of the entire international transportation network. Subsequently the international itinerary planning problem is solved on the customized network leading to a list of alternative generic itineraries, i.e., itineraries for which only the international transportation links are fully specified.

Keywords: Itinerary Planning; Multicriteria; Multimodal Transportation Network.

Résumé

Le travail présenté dans cet article vise à modéliser et à résoudre de façon multicritères les problèmes de la planification des itinéraires internationaux. Les problèmes de planification d’itinéraire émergents sont définis en prenant un compte un réseau de transport multimodal fonction du temps qui consiste en un ensemble hiérarchiquement interconnecté de réseaux de transport internationaux, interurbains et urbains. Les problèmes de planification d’itinéraire à l’étude se répartissent en deux grandes catégories: i) statique, et ii) dynamiques. La catégorie « statique » se réfère aux décisions de planification d’itinéraire prises en phase «pré-trajet» tandis que la catégorie «dynamique» se réfère aux problèmes de re-planification en cours de voyage. Une approche de solution globale a été développée pour résoudre les problèmes proposés de planification d’itinéraires internationaux. Cette approche implique une phase de pré-traitement dans lequel un sous-réseau international personnalisé est conçu et stocké pour chaque paire de pays d’origine et de destination potentiels du trajet international. Dans ce contexte, le traitement de n’importe quelle demande de déplacement ne fait intervenir que le sous-réseau personnalisé correspondant au lieu de l’ensemble du réseau de transport international. Ensuite le problème de planification de l’itinéraire international est résolu à partir du réseau personnalisé et conduit à une liste d’itinéraires alternatifs génériques, c’est à dire d’itinéraires pour lesquels seuls les liens de transport internationaux sont entièrement spécifiés.

Mots-clé: Planification d’itinéraire; multicritères; Multimodal Réseau de transport.

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1. Introduction

It is widely argued that providing travelers with door-to-door international multimodal journey planning services with real time alerting and on-trip re-planning capabilities constitutes a major need in the international travelers community. Based on a user requirements analysis performed recently within research project E-WISETRIP (Zografos et al., 2010) and given journey planning limitations of the existing journey planners, the major journey planning needs for international travelers include: i) the provision of door-to-door multi-modal itineraries addressing one-way, round-trip or multiple-trip journeys taking into account multiple criteria and user defined constraints expressing travelers special needs, and ii) on-trip re-planning capabilities addressing potential transport disruption incidents.

Covering the above journey planning needs involves dealing with two major categories of trip planning problems: static and dynamic. The static refers to journey planning decisions at the pre-trip phase and includes: i) the elementary itinerary planning problem defined within a given pair of origin/destination points within a given earliest departure and a latest arrival time at destination, ii) the return trip itinerary planning problem, iii) the itinerary planning problem with multiple intermediate stops, and iv) the trip itinerary contingency planning problem, i.e., planning in advance alternative back-up itineraries that may resolve several anticipated trip disruptions. The dynamic refers to the journey on-trip re-planning problem. The emerging itinerary planning problems are defined on the hierarchically interconnected international, interurban and urban transportation networks modeled as a multimodal time-dependent network.

The remainder of this section includes five sections. Section two presents the major features of the international itinerary planning problems addressed in this paper. Section three provides the network model of the underlying transportation network and specifies the models that express the itinerary planning problems covered in this paper. Section four provides an overview of the previous related work on modelling and solving itinerary planning problem on multimodal networks and section five presents the proposed solution approach. Finally section six outlines the major finding of this research.

2. Defining international itinerary planning problems

2.1. Elementary international multimodal itinerary planning problems

The objective of this problem is to determine the alternative itineraries between an origin and a destination for a given earliest departure time and/or a latest arrival time. In general each itinerary should include the sequence of transport services (transport mode, point of embarking, point of disembarking, departure time, arrival time, walking transfers) connecting the origin with the destination. The core part of any itinerary consists of a sequence of international transport segments between two terminals, and the intermediate interurban and urban transport segments (including walking) for executing the transfers between international terminals or between an international terminal and the origin or destination of the trip. The criteria taken into account in solving the above itinerary planning problem are the following: i) total travel time, ii) total number of transfers, iii) CO2 emissions per passenger, and iv) cost. Two major categories of constraints apply to this type of itinerary planning problem: i) time based constraints, and ii) mode based constraints. The former category of constraints involves the earliest departure time from the origin and/or the latest arrival time at the destination. The second category of constraints relates to the special needs of the traveler regarding the types of modes that cannot be used for executing the journey, e.g., exclusion of ships.

2.2. International round-trip itinerary planning problem

Round trip planning involves an itinerary planning problem in a multimodal transportation network aiming to specify alternative itineraries for an international trip with return given an earliest departure time from the origin, a latest arrival time at the destination, an earliest departure time from the destination back to the origin, and a latest arrival time back at the origin. A major feature of this problem is that the selection of an international transport mode for the forward trip may affect the alternative travel mode options and the associated costs for the return trip and vice versa. The criteria used for planning international round-trip itineraries are the same as in the one-way case. Concerning the time constraints, the earliest departure time from the origin and the latest arrival time at the destination and the earliest departure time from the destination back to the origin are essential scheduling parameters in order deal with the corresponding itinerary planning problem. In addition to time
constraints, mode-based constraints may also be relevant expressing the special needs of the traveler regarding the types of modes that cannot be used for executing the journey.

2.3. International multiple-trip itinerary planning problem

A multiple-trip includes a specified number of intermediate stops at various cities. The travelers stay at each intermediate stop and the corresponding arrival time at each stop is known in advance. This multiple trip requests may arise to both business and leisure travelers. Dealing with this type of multiple trip requests involves the solution of a itinerary planning problem aiming to determine alternative itineraries from an origin to a destination passing through a sequence of mandatory intermediate stops each one constrained by a latest arrival time and (possibly) an earliest departure time. The departure from the origin is also constrained by an (traveler-specified) earliest departure time, while the arrival at the final destination may be also optionally constrained by a latest arrival time. Each solution to the above problem constitutes an extended itinerary which includes sub-itineraries for executing all intermediate trips defined by the mandatory intermediate stops. The criteria and the constraints applicable for this problem are similar with those for the round trip itinerary planning problem.

2.4. International trip itinerary contingency planning problem

The contingency planning problem emerges from the international traveler’s need to build a contingency plan for his/her trip itinerary. In this type of journey planning problem, the traveler deals in advance with the possibility of a disruption in any of the transport segments of his/her trip itinerary. This is achieved by building at the pre-trip phase of his/her journey one or more back-up trip itineraries that may resolve a possible disruption scenario (e.g., cancellation of a flight). Building in advance this type of back-up plans to transport disruption scenarios involves the determination of alternative itineraries that may resolve the relevant travel implications. The solution of the arising trip redesign problem should take into account constraints that are bound by the initial trip itinerary, e.g., tickets for transport services already booked.

In more detail, the trip redesign functionality for contingency planning involves an itinerary planning problem where given an initial itinerary and a transport link (used in this itinerary) where a disruption is possible (though not confirmed), a revised itinerary is created from any stop before the potential disrupted link, which resolves the potential disruption. The major criteria for this problem is to minimize the additional cost and the additional travel time of the new trip. Thus, if any transport segment of the initial trip itinerary following the transport link hypothetically disrupted has been booked, the alternative trip itineraries are bound to using these booked services.

2.5. International dynamic itinerary re-planning problem

Dynamic re-planning of a trip aims to provide the traveler with alternative options of fixing his/her trip in real-time after a transport segment of his/her trip has been disrupted (service cancelled or departure/arrival delayed). Unlike the trip contingency planning problem, in this problem the alternative itineraries can only be built from the intermediate stop that the traveler is currently located in or heading to. The objective of the emerging itinerary planning problem is to determine an alternative sub-itinerary from its current location in the initial itinerary to the destination, taking into account that a transport service initially included in his/her trip itinerary is not accessible anymore (due to cancellation or increased delay). The alternative itinerary is calculated while the traveler is en-route taking into account the updated schedules (if available) of the underlying transport services. The overall goal of this itinerary planning task is to provide an itinerary that deviates the least from the initial plan, while it minimizes any possible additional cost and travel time. It is a similar problem with the one encounter in contingency planning however it may address more complicated situations where the underlying network changes in two ways: i) in terms of the schedule of the transport services, ii) in terms of the transport links (e.g., in case of cancellations).

3. Modelling issues

Any international trip involves a sequence of international transport services joined with transfers performed by interurban, and/or urban transport services. Thus, apart from leaving the origin or accessing the destination, the interurban/urban transport services are also used for transfers between different international transportation services. It should be pointed out though that any transfer may also involve a multimodal itinerary planning problem defined on an interurban or urban public transport system. However, in practice this local itinerary
planning problem is not addressed directly within the international itinerary planning problem. It is actually addressed by the traveler only after the international transport services have been determined. Thus, for planning purposes, any urban or interurban transfer is treated as a single transportation link with a proxy transfer time. Figure 1 presents schematically how the national/urban/local transfers are incorporated in the international network under study.

The underlying international transportation network is decomposed to a series of distinct international transport service sub-networks. An international transport service is defined as a transport service operated between two terminals located at different countries. The international transportation services are built on the basis of a set of terminals which represent the international gateways of each country defined as follows: an international gateway of a country is a station (or terminal) of a transport mode used by at least one international transport service. This definition implies that if an international transport service embarks/disembarks passengers to a series of stops within one country then in general any of these stops should be considered as international gateways.

Any transportation network may be modelled by a mathematical graph $G(N,A)$ where $N$ is the set of nodes and $A$ the set of links, taking into account the following assumptions: i) each link corresponds to a phase of a potential trip or an activity taking place within a trip, and ii) the nodes correspond to events delimiting the links as defined above (Cascetta, 2009). The above analysis suggests that the underlying international transportation network may be modeled by a graph $G(N,A)$ where, $N$ the set of international gateways (terminals of the international transportation services), and $A$ the set of arcs defined as $A = A_I \cup A_T$ where $A_I$ denotes the international transportation services, and $A_T$ the local or interurban transfer links. Nodes associated to the local transport services (e.g., bus stops, metro stations, etc.) are not considered in this network.

The international itinerary planning problems defined on the network described above are formulated as a time-dependent shortest path problem in multimodal transportation networks with multiple criteria and time windows. In the elementary, round-trip, and multiple trip itinerary planning problems, the expected outcome relates to a set of non-dominated paths. However, in the contingency planning and dynamic itinerary re-planning problems, the expected output relates to a single or a limited number of alternative solutions. Given these solution requirements
from the perspective of the user, the elementary, round-trip, and multiple trip itinerary planning problems are modelled as multi-criteria time-dependent shortest path problem in multimodal transportation network while the contingency planning and dynamic itinerary re-planning problems are modelled as lexicographically time-dependent shortest path problem in a multimodal transportation network. This paper provides an overall solution approach for addressing the former group of problems.

4. Previous related work

The multi-criteria shortest path problem has been widely studied in the literature (Hansen, 1980; Martins, 1984; Warburton, 1987; Mote et al., 1991; Pallottino and Scutella, 1998). It has been proved in (Hansen, 1980) that the number of non-dominated solutions may increase exponentially with the number of nodes in the network. Pseudo-polynomial forward label setting algorithms have been proposed for addressing the multi-criteria shortest path problem. A key feature of this type of algorithms is that each non-dominated path identified is represented by a multidimensional label which hosts the value of the path under each of the criteria under consideration. Starting from the origin, this type of routines construct iteratively new paths by extending the already identified non-dominated paths. At each iteration the lexicographically minimum label is selected and it is attributed as permanent. It can be proved that the lexicographically minimum label is non-dominated. Then new paths are created and by extending the corresponding recently identified permanent path with the relevant outgoing links from its tail node. It should be pointed out that the correctness of the label setting algorithms is founded on the fact that if a path is non-dominated then any of its sub-path are non-dominated too.

The adaptation of these routines for addressing the multi-criteria time-dependent shortest path problem is not valid in general. Similar forward label setting approaches have been proved to work only for non-decreasing cost attributes (Getachew et al., 2000). If travel time is also included in the cost attributes, then it is necessary that the FIFO property holds for every arc of the network (i.e., earlier departure time from the upstream node implies earlier arrival time at the downstream node, i.e., no over-passing is not allowed). However, in general the Belman’s principle does not hold and therefore, a forward label setting algorithm cannot be applied (Hamacher et al., 2006). Alternatively it has been proved that a backward label setting routine is valid for determining the non-dominated solutions to a multicriteria time-dependent shortest path problem (Hamacher et al., 2006, Androutsopoulos and Zografos, 2009).

A major issue that arises in shortest path problems defined on multimodal networks relates to the viability of a path. Each of a multimodal network represents a transport service between two consecutive stops. Thus, each solution of a shortest path problem (with single or multiple criteria) on a multimodal network represents a sequence of transport services used in order to travel from an origin to a destination. However, in practice not all possible combinations of transport services are eligible from the perspective of performing a trip. For instance, in an urban public transport system, if a traveler uses his/her private car in order to get to a metro station, then after getting out of metro it is not possible to use private car again. Similarly, in international trip planning if a traveler uses his private car to get to an airport, then upon arriving at the destination airport he/she cannot make use of private car again. Thus, in this type of problems, path viability should be considered in determining feasible itineraries.

In recent studies, the assessment of the viability of a path on a multimodal network is modeled through a deterministic finite-state automaton (Barrett et al., 2000; Lozano and Storchi, 2001; Gräbener et al., 2010; Gueye et al., 2011). Any partial path defined on a multimodal network is associated to a state which is specified by the sequence of transport services that it includes. In expanding the partial path to a new path through concatenating an outgoing arc from its last node, then a new state is determined for the new path. If this state lies within a given set of eligible states, the corresponding new path is viable.

Gueye et al. (2011) provided forward label setting and correcting algorithms for solving a bi-objective shortest path problem in a multimodal network, where the objective functions under consideration were travel time and number of transfers. Two alternative algorithmic approaches were presented. The first approach was based on the Chrono space algorithm (Pallottino and Scutella, 1997) which aimed at determining the non-dominated paths in a multimodal network in order of increasing number of transfers. The second approach aimed at determining the non-dominated path in an order of decreasing number of transfers and increasing travel time. Finally, Gueye et al. (2011) propose a bidirectional label setting algorithm which improves the computational efficiency of the label setting approach. In all algorithms proposed, the authors enhance the basic dominance rule to the state-based dominance rule, where one path may dominate another even if they are not on the same state.
It should be pointed out that the above algorithms are not applicable if the travel time is not FIFO or an additional criterion is included which is not a non-decreasing function of time. As a consequence this type of routines are not valid for the itinerary planning problem under study since the cost, which is an essential criterion in international tip planning, is not in general non-decreasing.

5. Algorithmic approach

The itinerary planning problems envisaged to be addressed are defined on a hierarchically structured multimodal transportation network which consists of a large set of distinct transportation services falling into one of three layers. The top layer includes any international transport services connecting international transport stations and terminals. The middle layer includes the national transport services connecting the international transport stations or terminals of each country. Finally at the bottom of the hierarchical structure there are urban/local transport services which connect international stations/terminals or national station/terminals.

Based on the description of the international transportation network under consideration two major issues arise: i) the emerging network is huge thus requiring substantial computational time for solving the relevant itinerary planning problems, and ii) a substantial part of the network would never be involved in any of the alternative trip itineraries for a given trip request.

A two-phase solution approach was developed for solving the itinerary planning problems taking into account the above issues. In the first phase of the approach a pre-processing takes place (off line) in which a customized international sub-network is designed and stored for each pair of potential origin and destination countries. This network includes only arcs and nodes of the top layer of the transportation network (Figure 1) which could be potentially be included in alternative itinerary. In this context, addressing any trip request involves recalling just the corresponding customized sub-network instead of the entire international transportation network. At the second phase of the approach the international itinerary planning problem is solved on the customized network leading to a list of alternative itineraries (i.e., itineraries for which only the international transportation links are fully specified). The remainder of this section analyses the proposed solution phases.

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**Fig. 2.** The two-phase solution approach dealing with the international itinerary planning problems.
5.1. Customized network

It is evident that using the entire international transportation network to identify alternative itineraries leads to a computationally burdensome task. Moreover, the entire international transportation network may include transport links that would never be included in a feasible itinerary due to time constraints. For instance, if the trip request is from Athens to London, then considering an itinerary that includes Moscow airport is not viable due to the extended time duration of the trip. A way of decreasing the computational effort required to determine alternative itineraries and avoiding non-viable itineraries from consideration, is to pre-process the underlying international transportation network by identifying (off-line) for every possible pair of origin and destination countries a sub-network that would include transportation links that could be possibly included in a viable itinerary. The pre-processing phase should be applied to any pair of countries covered by the system. The expected outcome for each pair of origin and destination countries is a network connecting the international gateways of the origin-country to the international gateways of destination-country, so that any path does not exceed an estimated maximum travel time of $L$ hours (e.g., 12 h). Note that the threshold value ($L$) may be different for different pairs of countries. The threshold value ($L$) applicable for a given origin and destination may be specified by the following steps: i) determine their direct distance ($D$) (from the longitude-latitude coordinates of the corresponding locations), ii) provide an estimate of the travel time ($T$) if this distance was covered by a direct flight (the use of an ad-hoc travel speed is needed), and iii) multiply the emerging time ($L$) with multiplier ($\lambda$), $\lambda > 1$, e.g. 1.5. Thus $L := \lambda T$, allowing for a flexibility in the size of the customized network. In particular, for larger values of $\lambda$ the larger the emerging customized network. The emerging customized network is static in the sense that its links correspond to transport connections with no timetable information. A major prerequisite for applying the pre-processing steps relates to the availability of a static version of the international transportation network with the following features:

- The static network involves a list of international gateways and a list of static links representing transport connections between the international gateways. The list of transfers (if any) between two gateways is also assumed available.
- Each node (gateway) is identified by its unique ID, while it is also associated to the following type of information: i) country, ii) longitude-latitude coordinates, iii) transport mode.
- Each link of the static network is identified by its two end-nodes (gateways) and a transport mode.

The following approach is proposed in order to determine the static network associated to a given pair of countries:

1. Specify all international gateways of both origin and destination countries
2. Apply a forward shortest path label setting algorithm from the origin-country gateways and a shortest path backward label setting algorithm from the destination-country gateways on the static international transportation network (Pallottino and Scutella, 1998).
3. Each time a (forward or backward) label is fixed for a gateway two issues are checked: i) if the gateway is already (backward or forward) labeled (so a path from an origin-gateway to a destination-gateway has been found) and ii) if the labeled gateway is connected (via transfer) to another gateway which is already (backward of forward) labeled. In both cases the travel time of the path is calculated (by adding the corresponding travel times of the constituent sub-paths). If the path travel time exceeds $L$ then the process is terminated and the links already associated to at least one identified path constitute the customized network for any trip request associated to the specific pair of countries. In practice the above process excludes any path of the static network for which a lower bound on its travel time exceeds the ad-hoc threshold value ($L$).

The travel time on any static link is calculated by the ratio of the distance (calculated from the gateways’ coordinates) with the ad-hoc set travel speed. This pre-processing phase is applied before solving any of the international itinerary planning problems.

5.2. Solution algorithm for the elementary international itinerary planning problem

The proposed solution approach for the elementary international itinerary planning problem includes two major stages. In stage I, the international part of the trip is identified, (i.e., sequence of international segments from the origin to the destination), including the walking/urban/interurban transfers where necessary (i.e., transfer from the origin to the first international gateway, the transfer from the last international gateway to the destination, and the transfers between international gateways. In this stage of planning the emerging paths are not fully defined in the sense that the transfer links are not fully specified (an indicative estimate for travel time is only used in this stage). As a consequence there are two issues pending to be specified in the second stage of the solution approach for each of the generic itineraries identified: i) determine the optimal (possibly multimodal) local/interurban itinerary for performing each transfer while retaining the overall feasibility of the entire
itinerary, and ii) validate that the complete itinerary (enhanced with the detailed transfer itineraries) remains optimal/non-dominated. Thus, is stage II each of the identified generic itineraries is further refined by identifying alternative transfer itineraries for performing the corresponding urban/interurban transfers.

In general, more than one alternative international gateways may be used in order to start or finish a journey. Thus, the itinerary planning problem under study is treated as a multi-criteria time-dependent shortest path problem with multiple origins and multiple destinations. Considering each destination separately, the emerging problem is decomposed to a series of multi-criteria time-dependent shortest path problems with multiple origins and single destination. A backward label setting algorithm is proposed for solving the arising multi-criteria path finding problem. The proposed algorithm incorporates the notion of buckets introduced in (Pallottino & Scutella, 1998) for time-dependent path finding problems.

Each $\lambda_k^{it}$ denotes the $k^{th}$ non-dominated label associated to node ($i$) and time ($t$) (where $t$ is assumed discrete) and consists of the following attributes: the total travel time $c_T(p_i^k)$, the total monetary cost $c_M(p_i^k)$, the number of transfers $c_i(p_i^k)$ and the CO2 emissions $c_E(p_i^k)$ of an itinerary $p_i^k$ in the underlying customised multimodal network connecting node ($i$) with destination ($d$). The set of non-dominated labels $\lambda_k^{it}$ for node ($i$) and time ($t$) is denoted by $A_{it}$ ($\lambda_k^{it}$ is the $k^{th}$ non-dominated label in $A_{it}$). The solution algorithm includes the following steps:

1. Initialise labels for the destination node ($d$): Set $\lambda_0^{it} := (0,0,0,0)$, for $t \in \{e,e+1,...,l\}$ ($e$ is the earliest departure time of the trip and $l$ is the latest arrival time) and place each label in the corresponding list (bucket) $B_i$.

2. For $t \in \{e,e+1,...,l\}$ do the following

2.1. For each label $\lambda_k^{it}$ in $B_i$ do the following:

2.1.1. Create a new label $\lambda_k^{it+1} := (c_T(p_i^k) + 1, c_M(p_i^k), c_i(p_i^k), c_E(p_i^k))$ which corresponds to the same itinerary with label $\lambda_k^{it}$ including one unit of time at node ($i$). If any of the new labels is non-dominated in $A_{i(t+1)}$ then insert it in $A_{i(t+1)}$ (disposing of any other existing label in $A_{i(t+1)}$ dominated by it) and in list $B_{i+1}$.

2.1.2. Create a new label $\lambda_k^{it} := (c_T(p_i^k) + c_T^e(j,i), c_M(p_i^k), c_i(p_i^k) + 1, c_E(p_i^k))$ for each transfer link ($j,i$) incoming to node $i$. Each of these labels corresponds to the itinerary from $j$ to destination $d$ which starts with the transfer link ($j,i$) at time $t'' = t - \tau(j,i)$ and continues through the itineraries associated to label $\lambda_k^{it}$. If any of the new labels is non-dominated in $A_{it}$ then insert it in $A_{it}$ (disposing of any other existing label in $A_{it}$ dominated by it) and in list $B_{it}$.

2.1.3. Create a new label $\lambda_k^{it} := (c_T(p_i^k), c_T^e(j,i,s), c_M(p_i^k), c_i(p_i^k) + c_M^e(i,j,s), c_E(p_i^k) + c_E^e(i,j,s))$ for each link ($j,i$) traversed by service $s$ at time $t''$ such that $t = t'' + \tau^s(j,i,s)$.

If any of the new labels is non-dominated in $A_{it}$ then insert it in $A_{it}$ (disposing of any other existing label in $A_{it}$ dominated by it) and in list $B_{it}$.

2.1.4. Remove $\lambda_k^{it}$ from list $B_{it}$, where $c_T^e$ denotes the total travel time on transfer link ($j,i$), while $c_T^e$ denotes the travel time, monetary cost, and emission when departing from $i$ to $j$. Repeating the above steps for each of the destination nodes, leads to the entire set alternative generic itineraries forwarded to stage II to specify alternative ways of realizing transfers.

5.3. Solution algorithm for the international round-trip and multi-trip itinerary planning problem

The round trip consists of two separate elementary problems. The questions that arises is whether one should address this trip planning problem as a single two stage problem or as two separate problems. Considering the total travel time of both trip phases, may be misleading in assessing two alternative solutions. For instance, say that there are two solutions S1 and S2 with total travel time 14h and 12h respectively. The second solution clearly dominates the first in terms of travel time. However it could be the case when the two phases of S1 have 7h duration while S2 involves phase 1 with 9h and phase 2 with 3h (e.g., due to schedule issues). In such a case the traveller may have favoured solution S1. Similar cases may exist for transfer time or the number of transfers.
This observation implies that the two problems should be addressed as two separate problems. Similar approach is suggested for the multiple trip planning problem.

6. Concluding remarks

This paper addresses modeling and algorithmic issues related to the international itinerary planning problem. The major categories of models associated with international itinerary planning have been determined. An algorithmic approach for solving the resulting large scale multi-criteria optimization models has been proposed. The proposed algorithm includes a pre-processing stage that contributes to the reduction of the problem size and makes the solution of the underlying models feasible in reasonable (for the types of models under consideration) computational time. The models and algorithms presented in this paper have been integrated into the E-WISETRIP international door-to-door journey planner. The system is under laboratory testing. Results regarding the computational performance of the proposed algorithmic approach will be reported as soon as they become available.

Acknowledgements

The presented research work was partially supported by the European Commission under the project Enhanced WISETRIP (E-WISETRIP).

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