

REVIEW

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Modelling connection trips to long-distance travel

Ida Kristoffersson^{1*} and Svante Berglund²

Abstract

Connection trips is often an important part of long-distance travel, especially for air travel. Models of long-distance travel would therefore benefit from a more detailed representation of the connection part. In this paper it is however shown that most models of connection trips are stand-alone models not integrated with the model for main mode. Only a handful models that integrate connection trip modelling into a large-scale transport model for long-distance travel are found. The connection trip models are classified into different types using a typology developed within the paper. The typology identifies nine model types that differ in how access/egress mode choice and terminal choice are handled. The scarce literature on connection trip modelling within large-scale transport modelling systems call for more research regarding detailed representation of access/egress mode choice and terminal choice, especially regarding the trade-off between model complexity and detailed representation, as well as whether the detailed representation of connection trips should primarily be conducted within the public transport network assignment or on the demand modelling side.

Keywords: Connection trip, Access trip, Egress trip, Access mode, Egress mode, Terminal choice, Station choice, Long-distance travel

1 Introduction

Large-scale transport models are often used in national transport planning and investment decision making, to calculate the potential future effects of transport investments/policy on aspects such as accessibility, safety, and CO₂ emissions (see e.g., Beser and Algiers [7], Rohr et al. [37] and Cascetta [12] for descriptions of large-scale national transport models in Sweden, UK and Italy, respectively). Many of these large-scale models of long-distance travel lack sophisticated modelling of connection trips. This is problematic since connection trips play an important role in many of the policy decisions that need decision support the coming years. For example, it is still not fully clear under which circumstances in Europe that the high-speed rail offer is competitive with

the air offer [18]. To analyse this question, access and egress plays an important role since airports are often located further away from city centres compared to railway stations. The main mode in-vehicle travel time and travel cost often give a much more complete description of the total trip for rail compared to air. An investigation of the Swedish national travel survey from years 2011–2016 shows that the cost for connection trips is a much larger part of the total trip cost for air (30–50%) compared to rail (in most cases below 10%) [6].¹ The same pattern is found for connection travel time. A long-distance model without a model for connection trips thus runs a risk of being biased towards air travel.

Another example is equity analyses of changes to accessibility for geographical areas where high-speed railway lines are built and after which some places no longer have direct connections, rather are faced with a connection trip to the new high-speed rail line [13].

*Correspondence: ida.kristoffersson@vti.se

¹ VTI Swedish National Road and Transport Research Institute, VTI/Box 55685, 10215 Stockholm, Sweden

Full list of author information is available at the end of the article

¹ We see no reason for this to be a particularly Swedish phenomenon – airports are located quite far from city centres compared to main train stations in most countries.

A third example is that connection trip modelling is also important to be able to evaluate investments such as a new rail line to an airport. New rail lines to airports have traditionally been evaluated by estimating a stand-alone model for access mode choice to the specific airport in question. Modelling of connection trips to long-distance travel is however not only relevant for air trips alone, but also for the choice of main mode for long-distance travel.

The complexity of the first and last part of a trip from the planning perspective is also highlighted in Nocera et al. [33], who develop guidelines for planners in order to reduce negative effects of first- and last mile mobility.

Previous reviews of research on connection trip modelling have focused on mode-specific issues related to connection trips such as railway station choice modelling [46] or airport access mode choice modelling [1]. The impact of access and egress on main mode choice has been researched more in a regional [26, 41] and urban context [30, 34], as well as in relation to crossing a maritime barrier [8]. This paper adds to existing literature by focusing not only on one main mode, but on how access and egress characteristics affects the choice between available main modes for long-distance travel in general, which is important for national/international transport planning purposes.

When reviewing the literature on connection trip modelling to long-distance travel, we noticed that there is a large variety in scope, from modelling of access mode choice to one specific terminal, to modelling of access and egress mode and terminal choice within a large-scale model of long-distance travel. To further understand and structure this wide scope, we develop in this paper a typology as a basis for classification of the literature on connection trip modelling. The aim of the typology is to span the room of choice dimensions² which could be analysed within the context of connection trip modelling, and thereby make it easier to understand and get an overview of this complex topic. Not all types in the typology are represented in the current body of literature, but they could be in the future. The nine types in the typology are further aggregated into three broader areas: stand-alone models of connection trips, large-scale models of mode choice for long-distance travel with focus on connection trips, and large-scale models of joint mode and destination choice for long-distance travel with focus on connection trips.

The contribution of this paper is threefold: First, a typology is developed which sorts models that include

connection trips into different types depending on the included choice dimensions; second, existing literature on connection trip modelling is classified and discussed within the context of the developed typology; and third, directions for future research are outlined given the identified research gaps.

2 Method

2.1 Literature search

A literature search has been performed in the databases Scopus, Web of Science and Google Scholar. The search terms that have been used are “access trip long-distance” and “access mode”. The literature search resulted in 33 relevant papers found. Backward snowballing added 3 more papers to the list. Furthermore, the authors had access to 13 relevant reports (grey literature) in the field of modelling access trips to long-distance travel already before conducting the literature search. All in all, this leads to 49 research items that the analysis in this paper is based upon.

2.2 Typology

Modelling of connection trips to long-distance travel can be done in several ways which differ in complexity. One of the most important characteristics is which behavioural choice dimensions that are included. The simplest connection trip model covers only access mode choice to a specific terminal, such as the choice between private car (parking and/or drop-off), taxi, scheduled airport bus, public transport, airport express train, shared ride van or hotel shuttle to get to a specific airport, or the choice between private car (parking and/or drop-off), public transport, bicycle or walking to get to a specific train station.

A slightly more complex connection trip model is a model of joint access mode and terminal choice in a region, typically a joint model for choice of departure airport and access mode to this airport. These models typically include the effect of flight frequency, characteristics of the access trip such as in-vehicle time, and flight fare levels (including low-cost options) for different segments such as residents/visitors and private/business trips.

The most complex model on the other hand, includes both access/egress mode choice and terminal choice in a complete model system for long-distance travel, which also includes main mode and destination choice, with the corresponding available access/egress modes for each main mode and available access/egress terminals for each origin/destination zone.

Because of this variety in model structures, a typology is developed in this paper which classifies models that include connection trips into nine different types, depending on which choice dimensions are included.

² There are theoretical combinations of choice dimensions that we have disregarded to keep the number of types down, e.g., models of access and egress mode choice as part of a model of destination choice only, since this model set-up does not make much sense.

Table 1 Description of the model types in the developed typology for connection trip modelling

Type	Description
1	Stand-alone models of access mode choice
2	Stand-alone models of terminal choice
3	Stand-alone models of joint access mode and terminal choice
4	Models of access and egress mode choice as part of a model for main mode choice
5	Models of terminal choice as part of a model for main mode choice
6	Models of access and egress mode and terminal choice as part of a model for main mode choice
7	Models of access and egress mode choice as part of a model for joint main mode and destination choice
8	Models of terminal choice as part of a model for joint main mode and destination choice
9	Models of access and egress mode choice and terminal choice as part of a model for joint main mode and destination choice

Table 2 Included choice dimensions of the model types in the developed typology for connection trip modelling

Type	Access mode	First terminal	Main mode	Destination	Last terminal	Egress mode
1	X					
2		X				
3	X	X				
4	X		X			X
5		X	X		X	
6	X	X	X		X	X
7	X		X	X		X
8		X	X	X	X	
9	X	X	X	X	X	X

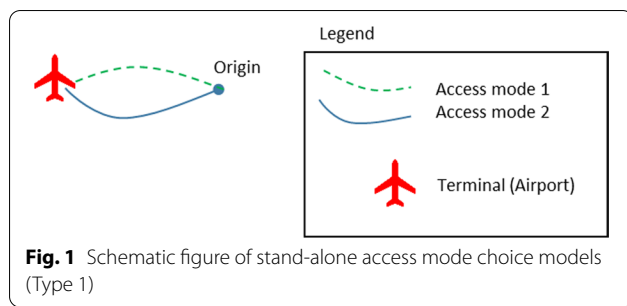
Table 1 describes the different model types in the typology and Table 2 shows which choice dimensions are included in which model type. The choice dimensions included in the typology are access/egress mode choice, access/egress terminal choice, main mode choice, and destination choice in nine different combinations. In the literature, these behavioural choices are usually modelled using discrete choice logit models based on random utility theory, assuming that the traveller chooses the alternative that maximizes utility, given a set of supply attributes such as travel time (depending on speed and distance), waiting time, and trip cost, with corresponding traveller valuations that depend on trip purpose and population segment [31, 40].

All types are theoretically possible, but it is not certain that they exist as implemented models. During the work with this paper, it has become clear that what constitutes a model of terminal choice is not self-evident. Any assignment of public transport trips to a network need to include some kind of terminal choice. In a standard model of travel demand, the choice of terminal is not the focus, rather an outcome of mode choice and network assignment. This does not exclude the possibility to model choices at the network level with a higher ambition

than just distribute trips with regard to departure frequency or some other measure of attractiveness. More advanced approaches in the network domain include enhancing the time resolution of the transit network, i.e., using the schedule in continuous time rather than representing time as averages of headways. Regardless of representation of time, assignment can be done with multimodal networks and using more sophisticated weighting schemes of the different components of travel impedance allowing for mode choice as a part of the network assignment. Further development of assignment routines based on logit-principles, where utility of travel components is the result of an estimation procedure, makes the distinction between network assignment and mode choice models to some extent diffuse or floating. The approach taken in this paper is a focus on mode and destination choice models that is not a part of a network assignment routine and thus qualify for a type in the typology which includes terminal choice (Type 2, 3, 5, 6, 8, and 9).

3 Results

In this section, results from the literature search are shown. The results are discussed in the context of the typology developed in the previous section. Models



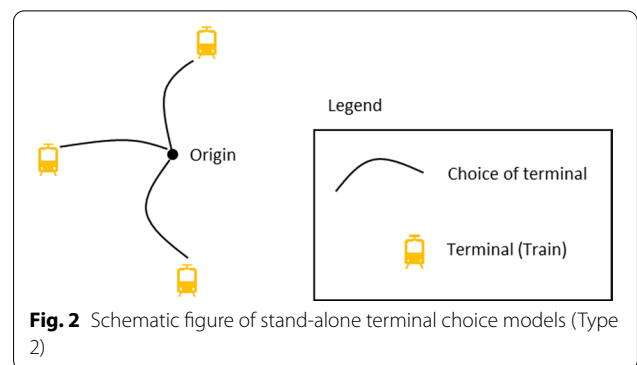
found in the literature are classified into the different types in the typology and the more advanced models are discussed in more detail. Only models that explicitly consider connection trips are included in the classification. In several large-scale transport model systems connection trips are handled within public transport route choice. Models where connection trips are represented by a very low speed on access/egress links, in order for the closest terminal to be chosen in most cases, and which do not include access/egress mode choice, are not included in the classification, as described in the previous chapter. There is however a grey zone here, since public transport assignment can be made more sophisticated using for example advanced route choice algorithms such as Path-Size Logit.

3.1 Stand-alone models of connection trips (Type 1, 2 and 3)

Most models found in the literature search belong to the category of stand-alone models for connection trips. This category includes three model types in the typology above—models of access mode choice only (Type 1—see Fig. 1), models of terminal choice only (Type 2—see Fig. 2) and models of joint terminal and access mode choice (Type 3—see Fig. 3).

The typical Type 1 model is a model of access mode choice to a specific airport. This type of model has been developed for several airports in the US [1, 2, 4, 24], Europe [5, 9, 10, 23, 43], and Asia [3, 14, 29, 36, 38, 39, 44, 45]. Also Type 1-models when rail is the main mode exist [42], even though it is not at all as common.

For rail it seems more common in the literature to focus on terminal choice only (Type 2-models, see Fig. 2) than access mode choice only. Young and Blainey [46] conduct a literature review with focus on terminal (station) choice (mainly Type 2- and Type 3-models). There does not seem to be similar bulk of literature on Type 2-models when the main mode is air, rather air studies seem to go directly from Type 1-models to Type 3-models in which access mode and airport choice is modelled jointly [22, 25, 27]. An example of a Type 3-model with rail as main mode is Debrezion et al. [17].

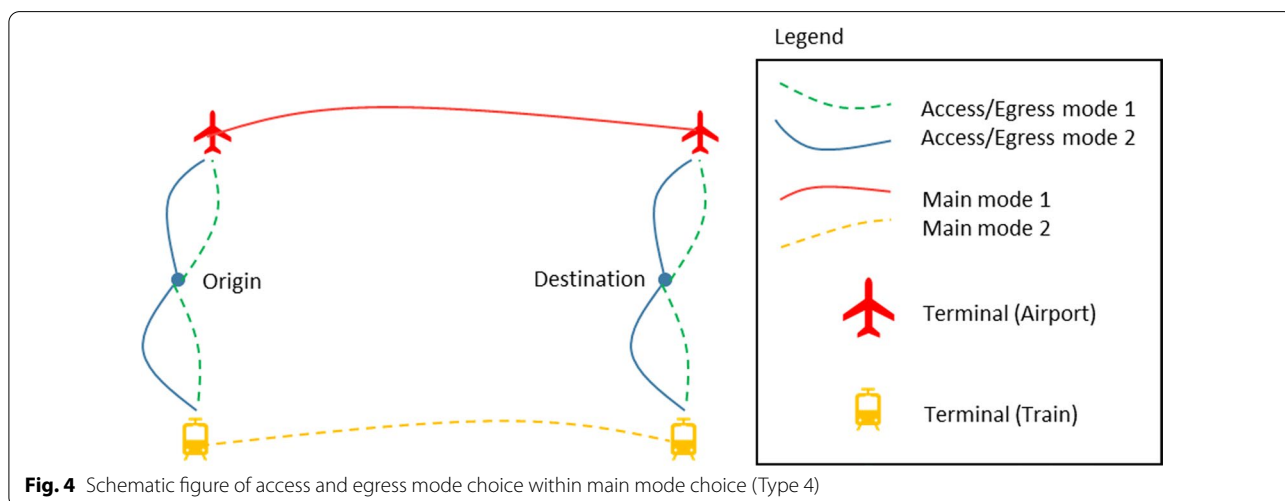
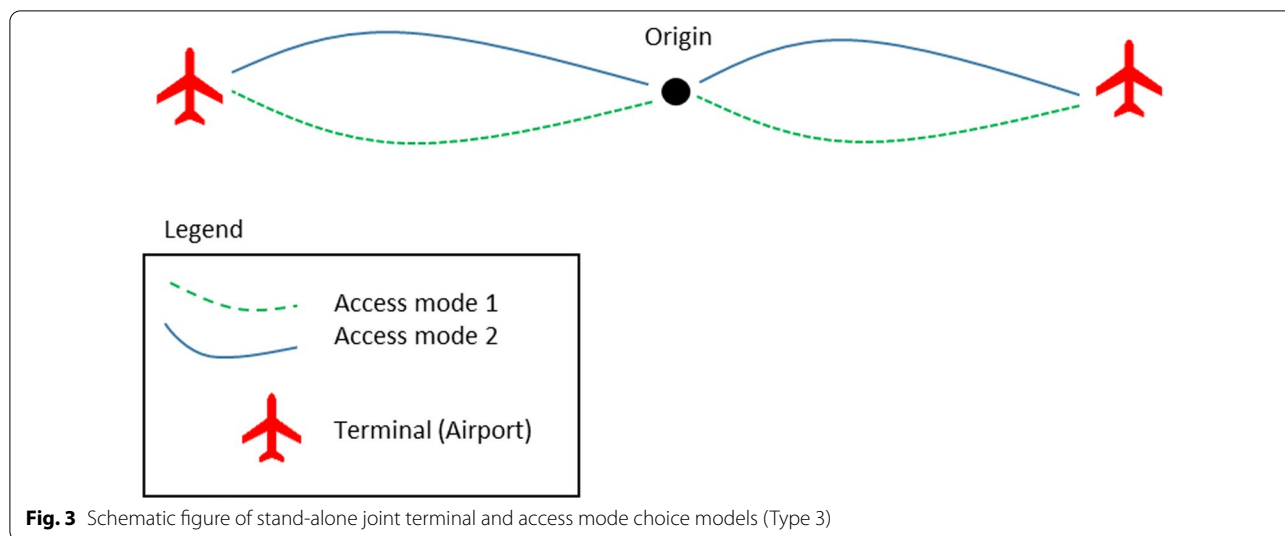


It is worth noting that none of the studies of Type 1–3 found in literature model access mode and/or terminal choice for long-distance bus, which is commonly included as a main mode in long-distance travel models. Kristoffersson and Berglund [6] show that 4.3% of long-distance trips within Sweden are conducted with bus as main mode, thus this is a minor mode even though not entirely negligible. It is probable that long-distance bus is more similar to rail than air regarding the share of travel time and travel cost related to the connection trip, since bus terminals often have central locations, just as train stations.

3.2 Large-scale models of mode choice for long-distance travel with focus on connection trips (Type 4, 5 and 6)

The models included in Type 4, 5 and 6 in the typology (see Figs. 4, 5, 6) has in common that they include main mode choice but not destination choice. In this case destination choice is fixed. It is thus assumed that long-distance travel destination choice does not depend on level-of-service variables such as travel time and travel cost, which is a rather strong assumption in many cases, especially if the model is used to forecast travel patterns 20 years or more into the future. The advantage is a simpler model structure which is easier to estimate and implement since destination choice typically generates a very large number of alternatives.

Type 4-models (Fig. 4) include main mode choice in combination with access/egress mode choice but not terminal choice. The CHSR California high speed rail ridership and revenue model (Cambridge [11] is the only Type-4 model found in the literature. This is an advanced model with main modes car, air, and rail (divided into high-speed rail and conventional rail), where access and egress mode choice has been estimated simultaneously with main mode choice. This allows control over cost and travel time parameters in different parts of the model such that the parameter orders of magnitude are reasonable. The cost parameter is for example set equal

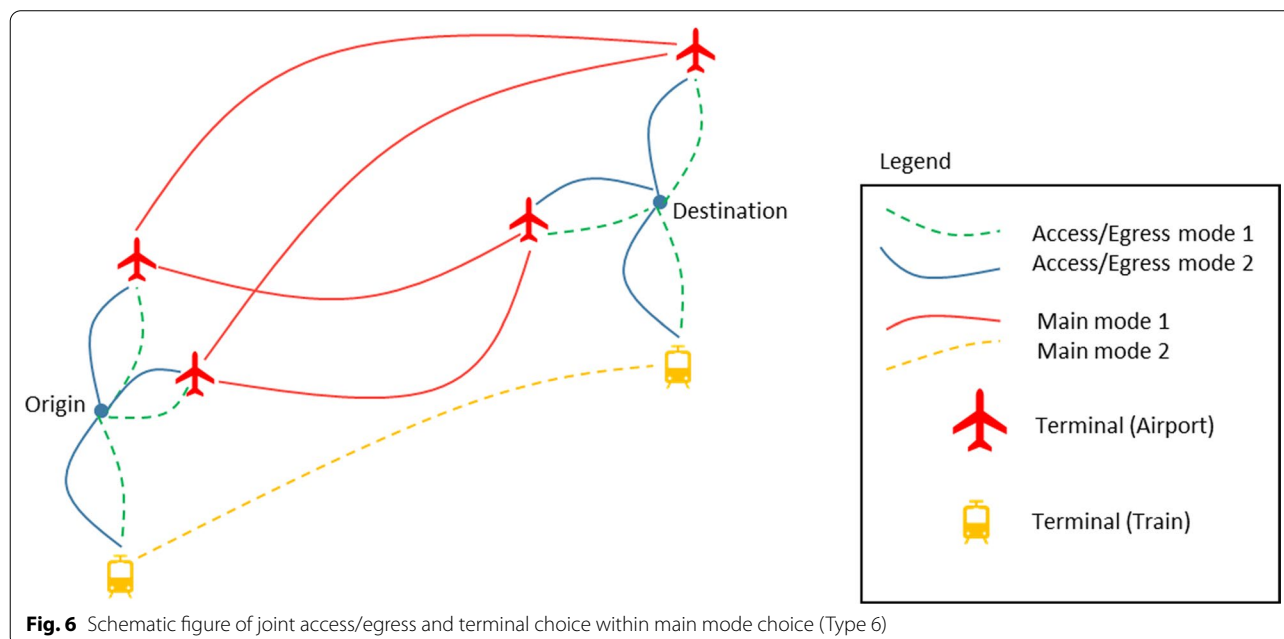
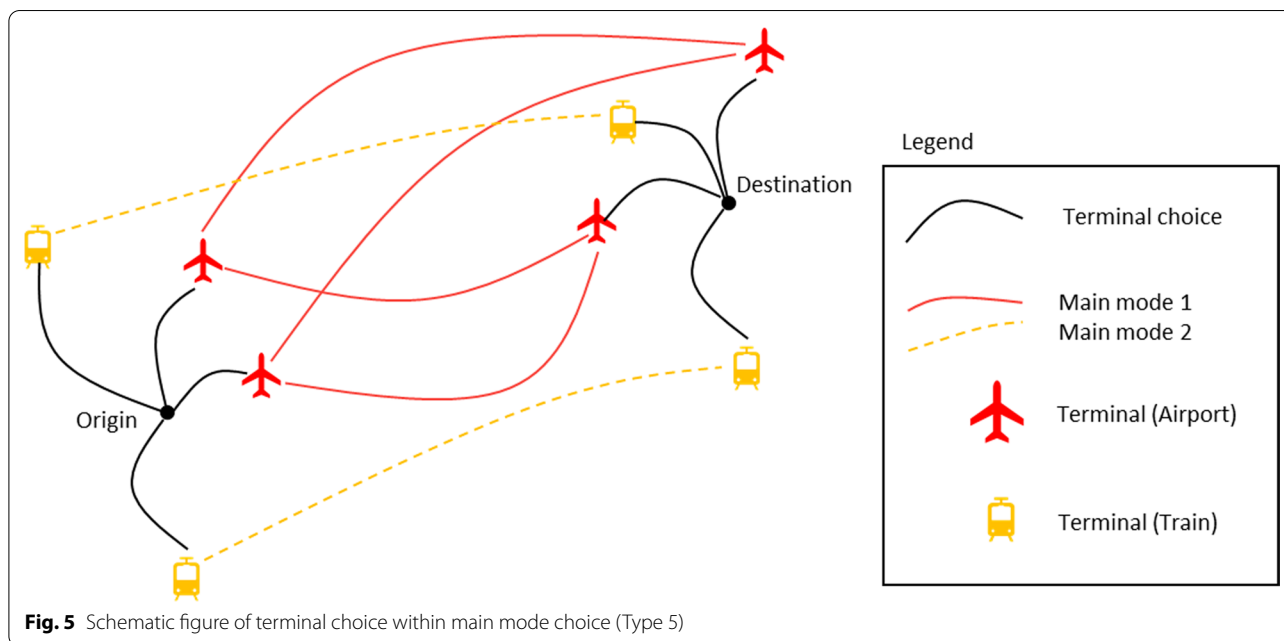


for different types of trips (access/egress/main) since valuation of money normally does not change during a trip. Travel time sensitivity may on the other hand differ between different types of trips and these are therefore allowed to vary within limits, e.g., that the sensitivity to access/egress travel time needs to be equal or larger than sensitivity to main mode travel time. Access and egress modes are modelled to air, high-speed rail, and conventional rail. The access/egress modes included are, for all main modes, car as a driver (parking), car as a passenger (escort), taxi and public transport.

Type 5-models (Fig. 5) include main mode choice in combination with terminal choice but not access/egress mode choice. The only Type 5-model found in the literature is a model called R³Logit for long-distance trips in North Carolina, USA [32]. This model includes car and

public transport (divided into bus, rail, and air) as main modes. It is assumed that car is used as access and egress mode to all public transport modes. For the public transport main modes, choice of terminal is determined by selecting the three terminals closest to the origin of the trip and the three terminals closest to the destination. Utility is then calculated for each of the nine combinations of start and end terminals and the station combination with highest utility is chosen.

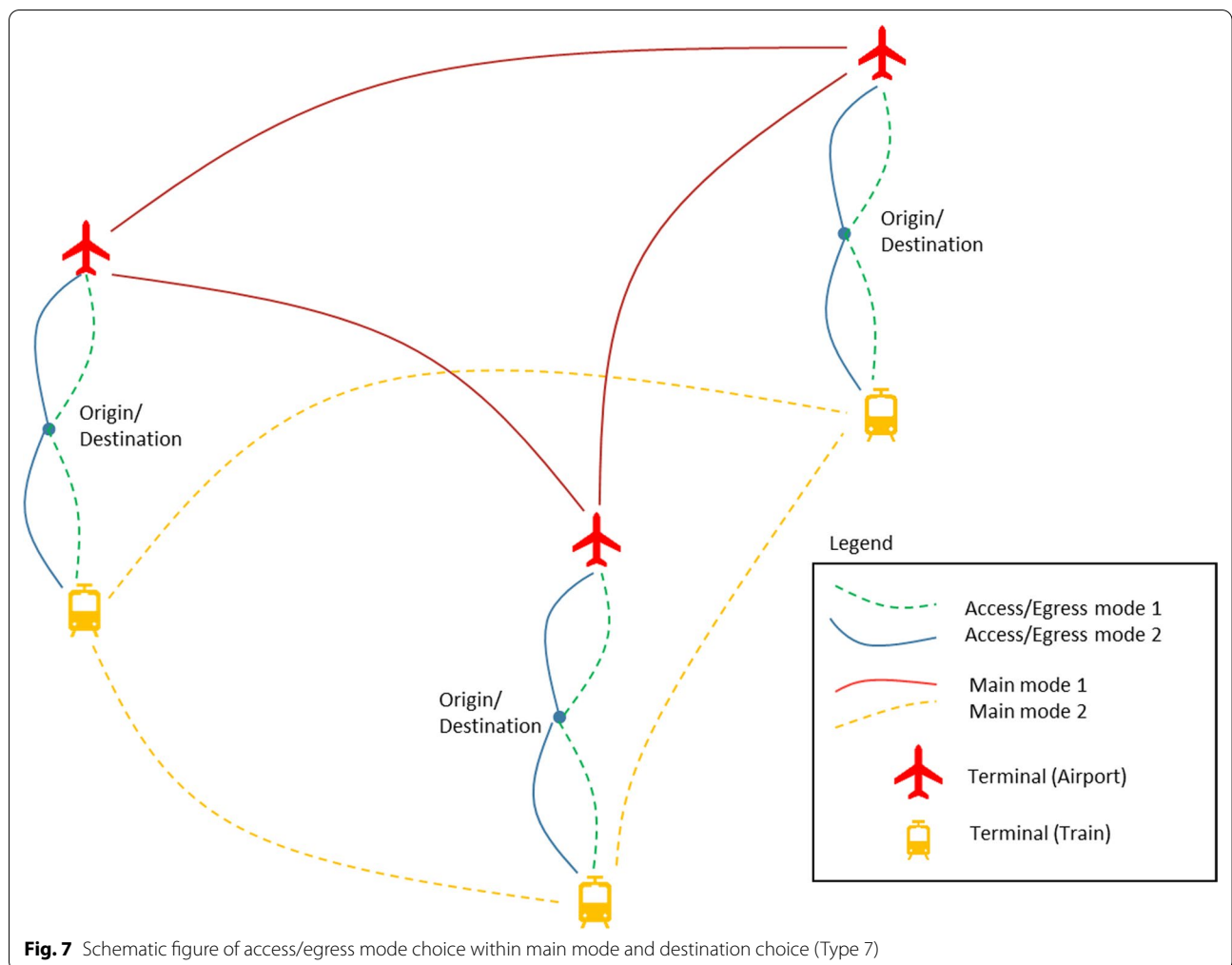
Type 6-models (Fig. 6) include main mode choice in combination with access/egress mode choice and terminal choice. The only model of this type found in the literature is a model for evaluation of high-speed rail in the UK called PLANET [28]. The PLANET model includes car, rail, and air as main modes. For rail as main mode it also includes a module for connection



trips. The module for connection trips is a nested logit model with rail access mode choice (car or public transport) on the higher level and choice of station pair (first and last station) on the lower level. Egress mode choice is not modelled explicitly. Allowed stations are chosen from a catchment area, with 20 stations as maximum number of possible stations. The catchment areas are larger for car compared to public transport.

3.3 Large-scale models of joint mode and destination choice for long-distance travel with focus on connection trips (Type 7, 8 and 9)

The models included in Type 7, 8 and 9 in the typology (see Figs. 7, 8, 9) has in common that they include main mode choice as well as destination choice in combination with connection trip modelling. These are thus



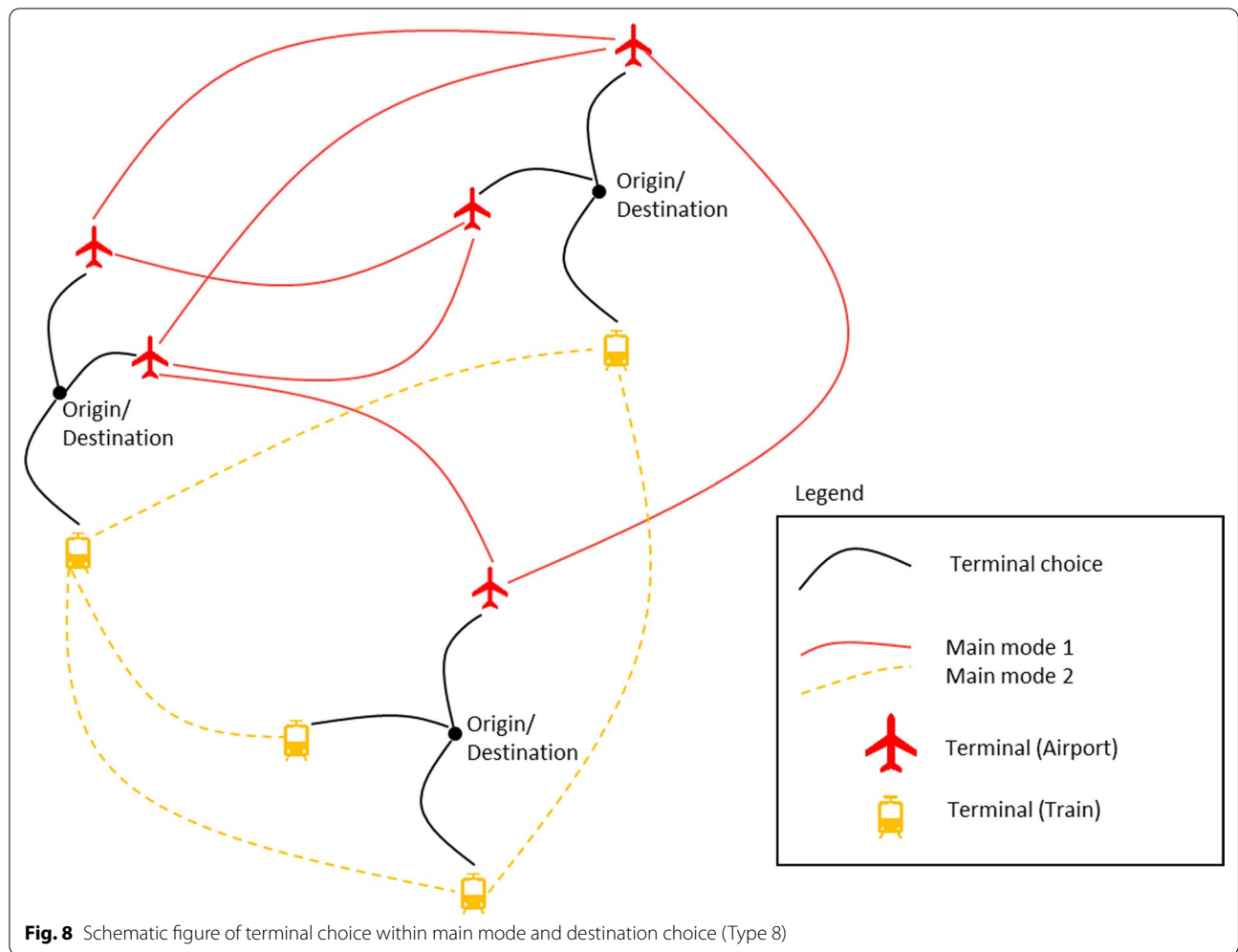
detailed and often very complex models where it is not obvious how the model should be structured.

Type 7-models (Fig. 7) include main mode and destination choice in combination with access/egress mode choice but not terminal choice. No long-distance transport model of this type was found in the literature search.

Type 8-models (Fig. 8) include main mode and destination choice in combination with terminal choice but not access/egress mode choice. Only one possible candidate for a Type 8-model was found in the literature search. This is the French national transport model called MODEV [16]. This model includes choice of destination and choice between the main modes road, rail, and air. Accessible documentation is limited but point out that several station-to-station level-of-service matrices are compared for each trip, based on which the best route is chosen.

Type 9-models (Fig. 9) include main mode and destination choice in combination with access/egress mode choice as well as terminal choice. In the literature search

the only long-distance model of Type 9 found is the Netherlands national transport model called LMS [20], which has been extended over the years to include more sophisticated modelling of access trips to rail [35]. The LMS model is not a model dedicated for long-distance trips only, rather it models all trips in the Netherlands and therefore includes the main modes car as driver, car as passenger, rail, bus/tram/metro, walk and bicycle. For rail as main mode, the model structure includes as many as seven choice levels in the decision tree: (1) tour generation, (2) main mode, (3) time of day (morning peak, evening peak or off peak), (4) destination zone, (5) access and egress mode, (6) embarking and disembarking stations, and (7) train. These seven choice levels are modelled using three separate logit models with logsums connecting the models and iteration performed to ensure convergence. The choices are combined as follows: tour generation, main mode / time of day / destination zone, access and egress mode / embarking and disembarking stations / train. The utility for train choice includes



variables in-vehicle time, ticket cost, boarding and transfer waiting time, and number of transfers. There does not seem to be any variables specific to access/egress mode or embarking/disembarking station other than that these choices may affect the variables mentioned above.

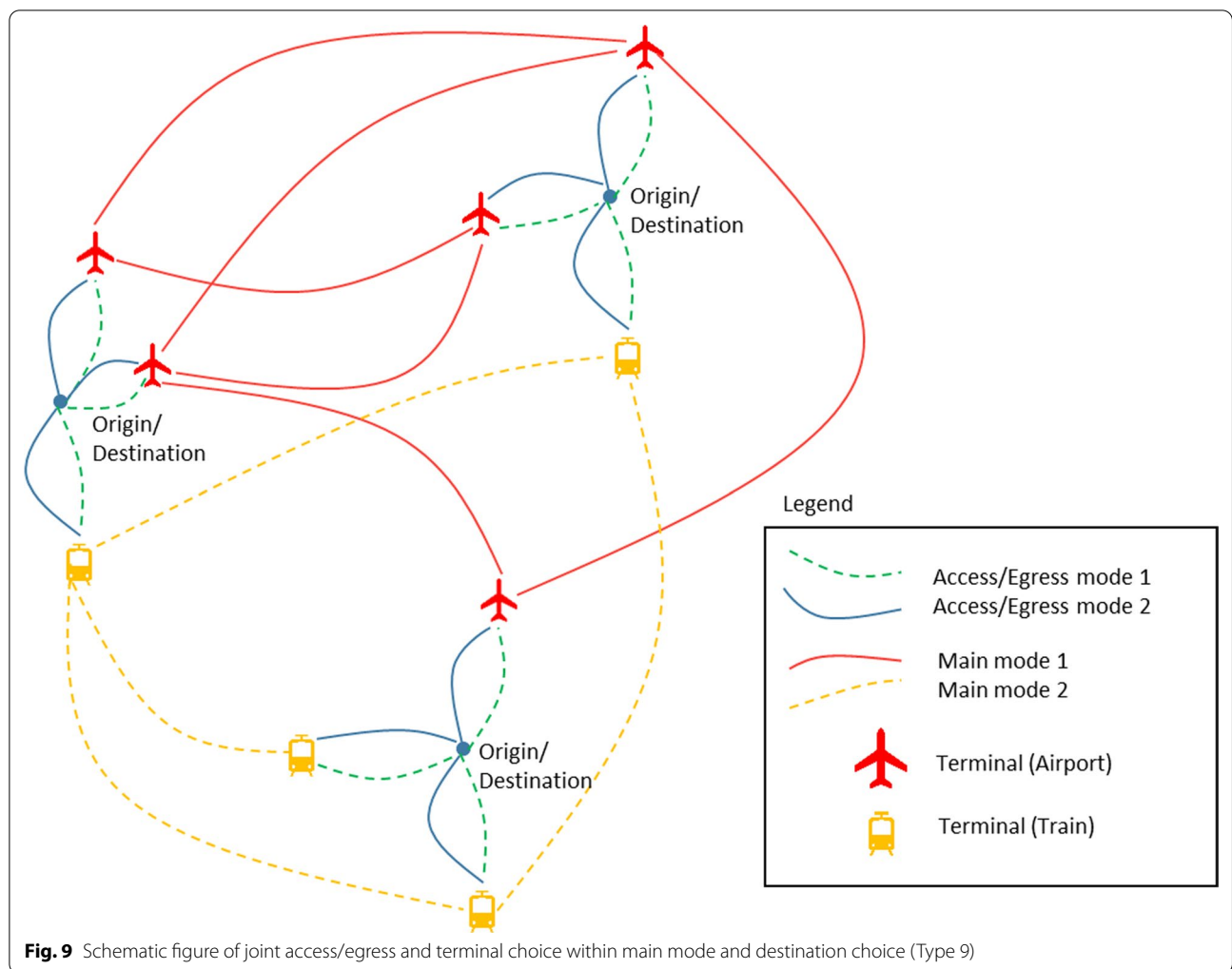
Two models of primarily regional trips have been found that model connection trips in a sophisticated way—the PRISM model for West Midlands in the UK [19] and the STM model for Sydney [21]. The PRISM model was an early attempt to model park-and-ride at rail and metro stations, and the model therefore includes the access modes car—parking, car—drop off, and other (walk, bicycle, and bus). Connection trips are modelled as a nested logit model with access mode choice above station choice. Last terminal and egress mode choice is not modelled explicitly.

The STM model for Sydney includes the main modes car as driver, car as passenger, public transport (train and bus), bicycle, walk and taxi. Three access modes to train are included: car as driver, car as passenger and other

(walk and bus). Terminal choice is included for the access modes car as driver and car as passenger and a previous version of the model is used to determine the five most attractive terminals for each trip. There are as much as six choice dimensions in the model: choice of main mode, public transport mode, access mode to train, train station, destination and charged or non-charged road. One of the major challenges in the development of the STM model was therefore to develop the nesting structure of all choice dimensions.

4 Research gaps and directions for future research

In this paper it is shown that most models of access/egress mode choice and terminal choice are stand-alone models not integrated with any model for main mode and destination choice. Stand-alone models are useful for analyses of e.g., access modes to specific airports or railway stations. The disadvantage is however that the detailed description of the connection trip is not put to good use in the main model for long-distance travel.



On the contrary, stand-alone models need external origin–destination matrices from a long-distance model as input.

In this review, we find a handful examples of models which integrate connection trip modelling within a long-distance model framework, see Table 3.

The seven existing models show that integrating access/egress mode choice and/or terminal choice into large-scale systems of long-distance travel is feasible. Given that the connection trips are often a large part of the generalised travel cost, especially for air travel, the motivation for a more sophisticated connection trip modelling is strong.

However, adding access/egress mode and terminal choice dimensions to an already large model structure will inevitably make the model more complex. Therefore, it is necessary that the sophisticated connection trip modelling is tailored towards the application area of the transport model. The developers of the models

reviewed in this paper have chosen different ways to tailor the models—e.g., by setting the destination choice as fixed or by limiting the number of terminals possible to choose between in the terminal choice. In the end, how the model should be tailored, is dependent on the application area the model is developed for. In general, however, more research on the trade-off between model complexity and detailed representation of connection trips is called for. Research concerning if connection trips are best handled within the public transport assignment or on the demand modelling side is also called for.

In general, connection trip modelling is likely to become even more important in the future as new mobility solutions for first-/last-mile access and egress trips are emerging, such as electric and/or automated bus shuttle services [15]. The future role of electric and/or automated vehicles is still unclear, e.g., whether they will serve as a complement or competitor to public transport,

Table 3 Overview of large-scale transport models including sophisticated modelling of connection trips

Name	Region	Type 4	Type 5	Type 6	Type 7	Type 8	Type 9
CHSR	California, USA	X					
R ³ Logit	North Carolina, USA		X				
PLANET	HS2 area, UK			X ^a			
MODEV	France					X	
LMS	The Netherlands						X
PRISM	West Midlands, UK						X ^b
STM	Sydney, Australia						X ^c

^a Egress mode choice is not included

^b Egress mode choice and terminal choice for the last terminal is not included

^c Egress mode choice and terminal choice for the last terminal is not included

or a mix of the two, and the role policy will have in this development.

5 Conclusions

In this paper, transport models that include handling of connection trips to long-distance travel have been reviewed. Since connection trip models are of many different types and have very different scope, a typology has been developed within this paper which classifies the models into different types depending on which behavioural choice dimensions are included. It is shown that most models of connection trips are stand-alone models of access mode choice or terminal choice to airports and railway stations. Only a handful transport models integrate sophisticated connection trip modelling into a large-scale model framework for long-distance travel mode and destination choice. However, those that do exist show that including sophisticated connection trip modelling is feasible, even though they require large data sets for estimation and calibration.

National transport models, that typically include main modes such as air, train, and private car, would benefit from an integrated approach to connection trip modelling as part of the long-distance travel framework, in which access mode choice with attributes such as access travel time and access travel costs are part of a nested logit structure for main mode/access mode/egress mode/destination choice. One of the main benefits of integrating connection trip modelling into the larger framework for long-distance travel is to have control over the valuations of travel time and travel costs in the different modelling parts. For example, it is recommended that the valuation of access travel time is equal or higher than the valuation of main mode travel time, otherwise unrealistic effects can appear with travellers avoiding the main mode. It is clear from this review that model application area is central when it comes to how connection trips should be handled. If station localisation is a

central application area for the model, then it should also be considered if sophisticated terminal choice should be included.

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Author contributions

Both authors have contributed significantly to all parts of the paper, except the figures which have been developed by Svante Berglund alone. Both authors read and approved the final manuscript.

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Data availability

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Declarations

Competing interests

The authors have no competing interests in relation to the paper.

Author details

¹VTI Swedish National Road and Transport Research Institute, VTI/Box 55685, 10215 Stockholm, Sweden. ²WSP Advisory, Stockholm, Sweden.

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