Technical University of Denmark

The usability of passenger delay models in socio-economic analysis

Thorhauge, Mikkel

Publication date:
2010

Document Version
Publisher's PDF, also known as Version of record

The usability of passenger delay models in socio-economic analysis

Mikkel Thorhauge, M.Sc., MT@transport.dtu.dk
Department of Transport, Technical University of Denmark
Building 116 vest, room 106A, 2800 Kgs. Lyngby

Abstract

The following paper discusses how a passenger delay model can be used in socio-economic calculations. At present passenger delays are often omitted in the modeling phase and therefore not included in the analysis. By using a passenger delay model passenger delays can be included in a cost-benefit analysis. Including passenger delays in the cost-benefit analysis will increase the level of details and thereby improve the accuracy of socio-economic analysis. In this paper the third generation passenger delay model is used. This model is the newest and most detailed passenger delay model created so far.

The main problem when including passenger delays is to determine the value of time for passenger delays and how to include the delays in a socio-economic analysis. This is due to the fact that passenger delays are not defined unambiguously. In general, delays can occur on different parts of a journey; while the passengers are waiting for the train (waiting time, first waiting time or even hidden waiting time) or while the passenger are sitting in the train (or bus). Furthermore a delay can also be negative, meaning that a passenger will arrive before planned (a so-called negative delay). It is necessary to consider how to define the value of time for the different types of delays as well as how to include these elements in a cost-benefit analysis.

This article proposes that a delay is defined solely by the difference between the scheduled and realized arrival time. The recommendations are listed as follows:

- The value of time for a delay is defined as done by the *Danish Ministry of Transport* (Trafikministeriet, 2003) no matter how or when the delay has occurred. The size of the delay is calculated solely by the difference between the planned and realized arrival time.
- A negative delay is defined as the value of time of hidden waiting time. A negative delay is calculated as the difference between the planned and realized arrival time and is considered a surplus in the cost benefit analysis
- A delay will not be included if the passenger arrives at his or her final destination on time even though the passenger may have experienced a delay (or travelled along a different route than planned) during the journey.

Note that this paper is regarded as a prequel to the article "*Optimization of timetable supplement from a passenger based socio-economic point of view*" (Thorhauge, 2010). This article is based on the results of (Thorhauge & Piester, 2010).

Keywords: Passenger delay model, socio-economic, public transportation.

Introduction

When public transportation is modeled, delays are normally disregarded and therefore not included in the socio-economic analysis. However delays (or the avoidance of delays) are a significant element for passengers using public transportation. By modeling with passenger delays (and thereby including the passenger delays in the socio-economic analysis) will improve the level of details in the overall cost-benefit analysis. Furthermore the passenger delays can be used to optimize the timetable supplement making the overall public transportation network more coherent.

The third generation passenger delay model

In the following a short introduction to the passenger delay model will be given. Thereafter the problems regarding implementation of the passenger delay model in socio-economic analysis will be discussed. The latest and so far most accurate passenger delay model (third-generation model) computes the passengers' route choices based on a given utility function. In theory this route choice calculation is done following the principles of any other schedule-based public route choice model. What makes the passenger delay model different from other models is that the third generation passenger delay model calculates delays by the following two steps;

- Step 1: Calculate the route choice (in order to minimize the "cost" of the trip[1]) based on the scheduled timetables – this will determine which route the passenger will use in an ideal situation where no delays occur.
- Step 2: Calculate the travel time based on the realized timetables following the route from step 1 (if possible) – this will estimate the travel time in case of delays.

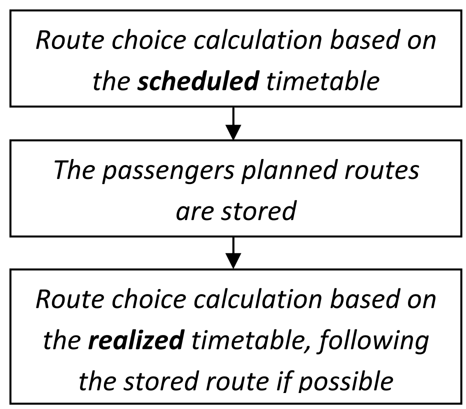

Figure 1: *Principle of the third generation passenger delay model. Based on* (Landex & Nielsen, 2006).

To sum up; the third generation passenger delay model takes account of delays by first calculating the passengers route choices based on the planned timetable (in technical terms called the *timetable of reference*), after which the route is stored. This is known to be the optimal route in the delay-free public transportation network that is investigated (according to the utility function). Basically the route choice is equivalent with a schedule-based public route choice model without delays. Afterwards the passenger delay model recalculates the passengers trip (stored from step 1) using the realized timetable.

If the passenger gets delayed beyond a specified threshold the passenger delay model will recalculate his or her route from that point (using the realized timetables). For further information about the passenger delay model see (Frederiksen & Brun, 2008), (Bagger, 2009), (Seest, Nielsen & Frederiksen, 2005) and (Landex & Nielsen, 2006).

[1] "Cost" according to the given utility function.

Determining delays

The passenger delay model does not calculate the actual passenger delays, but the travel pattern and travel time in case of delays. To estimate the delays it is therefore necessary to know the travel time in case of delays as well as when no delays occur. The difference between the travel time in the two scenarios must be considered a delay. Therefore it is necessary to run the passenger delay model twice:

- Calculation 1: First the model must be run with both the realized and scheduled timetables – this will calculate the travel time during delays.
- Calculation 2: Second the model must be run using only the scheduled timetables – this will calculate the travel time in case of no delays

The difference between the two calculations must be considered a delay. However determining the delay is not always a straight forward process. The problems and how to solve these are discussed in the next chapter.

How to interpret delays and the cost thereof?

The following chapter discusses how the passenger delay model can be used in socio-economic calculations. The main problem with using the passenger delay model in socio-economic analysis is how to define the delays in the first place, and second how to define the value of time, VOT, for different types of delays. The value of time is not necessarily uniquely defined since a delay can occur in different ways during the journey, e.g. during waiting time, hidden waiting time, first waiting time or during the ride itself. It is not given that the VOT for these different types of delays is identical. The official VOT's is published by (Modelcenter, 2009) as shown below:

Time element	Weightings (according to driving time)	Home-work [DKK/hour]	Business [DKK/hour]	Education and other [DKK/hour]	Weighted average [DKK/hour]
Driving time	1	79,03	332,99	79,03	92,60
Delay	2	158,07	665,99	158,07	185,19
Hidden waiting time	0,8	158,07	665,99	158,07	185,19
First waiting time	2	63,23	266,40	63,23	74,08
Waiting time	2	118,55	499,49	118,55	138,89
Changing time	1,5	7,90	33,30	7,90	9,26
Change penalty (DKK per change)	-	79,03	332,99	79,03	92,60

Table 1: *Value of time for public transport. Source:* (Modelcenter, 2009).

The table shows that *delays* are priced twice as high as *driving time*. This means that for each hour spent on driving time the passenger "lose" 92,60 DKK in a socio-economic point of view, while one hour spent on delay is worth 185,19 DKK for the passenger.

A simple example is a passenger arriving at station A at ´07. The train has a scheduled departure from station A at '10 and a planned arrival at station B at '20. Assume that the train is delayed by one minute at the arrival at station B, as illustrated below:

Minutes	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22
Scheduled timetable																
Realized timetable	First waiting time							Driving time						Delay		

Table 2: *Example of a situation where delays can be uniquely defined as prolonged driving time.*

In this case it is straight forward to calculate the socio-economic value of both the planned and realized timetable since there is no doubt on how to interpret the delay according to (Trafikministeriet, 2003). Clearly the delay occurs (and is experienced by the passenger) as one minute prolonged driving time. The socio-economic value of the realized trip is therefore calculated as (assuming 1 passenger in the train):

$$Socio\ economic\ value = 3\ min \cdot \frac{185{,}19}{60} DKK/min + 10\ min \cdot \frac{92{,}60}{60} DKK/min + 1\ min \cdot \frac{185{,}19}{60} DKK/min = 27{,}78\ DKK$$

However more complex situations will give rise to different ways of implementing the VOT's from table 1. Imagine an example as above where the first train is delayed, but the passenger have a planned transfer at station B in order to get to his or her final destination at station C as illustrated below:

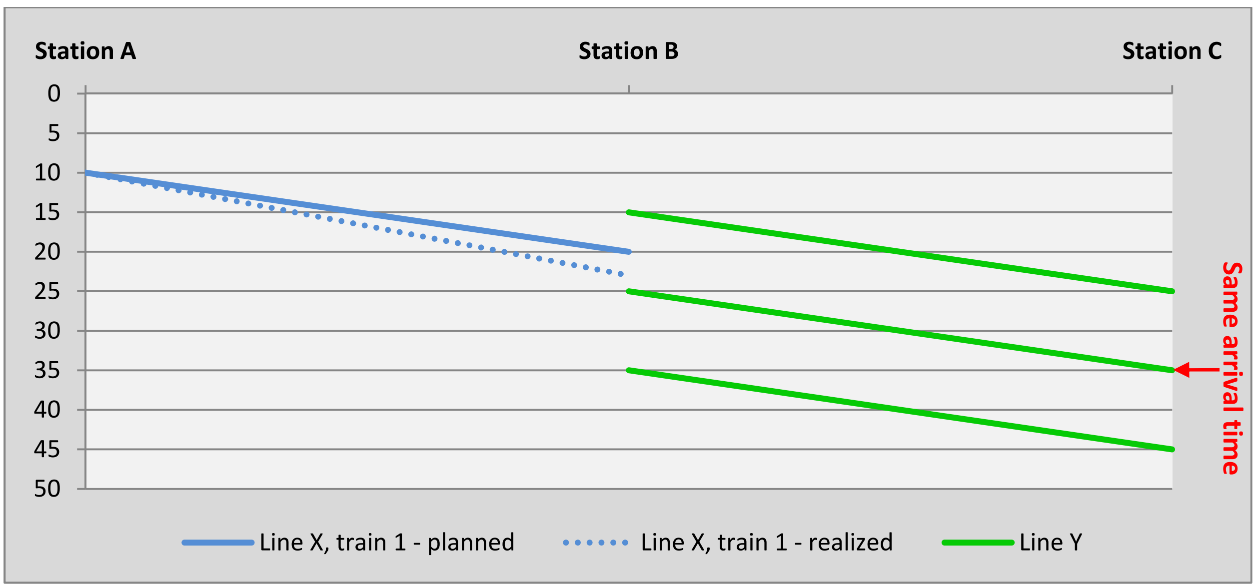

Figure 2: *Example of a delay which can be considered negligible.*

In this example the passenger is delayed when arriving at station B. However since station B is a transfer station for the passenger, the passenger will have to wait anyway for the second train, which is assumed to be on time. In the end the passenger arrives on time to his or her final destination, meaning that the passenger is not obstructed from attending any planned activities at the final destination.

The problem here is whether or not it is a nuisance if a passenger is delayed at a transfer station if the passenger is on time at his or her final destination? Or said in more general terms; is a delay along a journey considered a nuisance if the passenger is on time at his or her final destination? And if so; how should the nuisance be priced in a socio-economic analysis?

Assume another example where the situation is similar to the example above; the first train is delayed, but this time the delay is beyond a specific point where the passenger misses the correspondence with the second train as illustrated below:

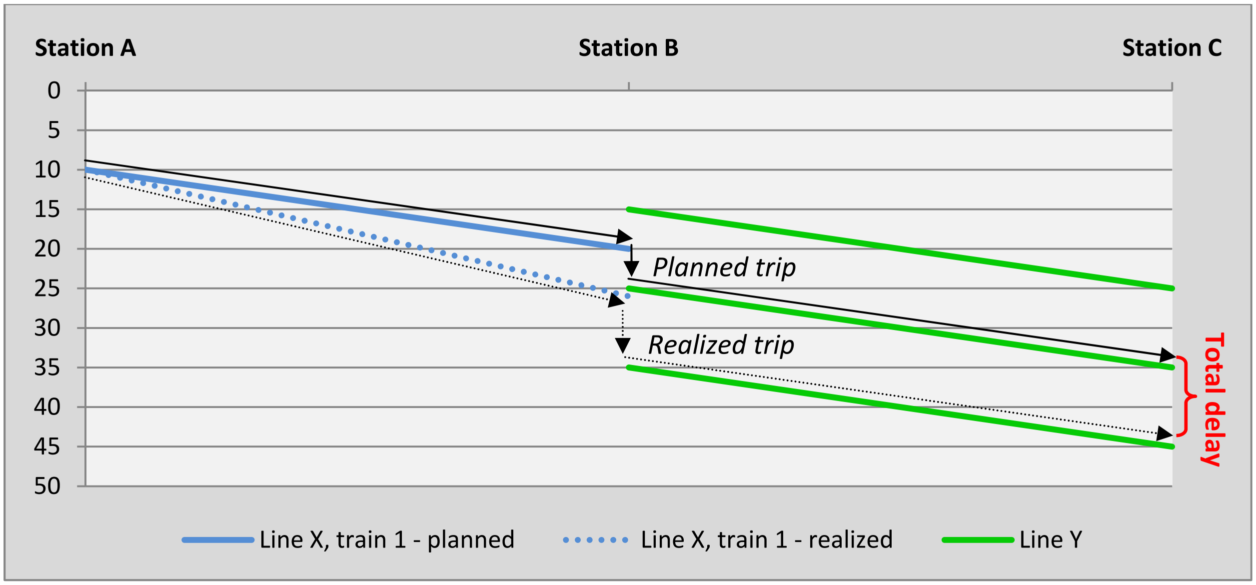

Figure 3: *Example of a delay which occurs a different time elements; prolonged driving time and prolonged waiting time.*

In this example it must be considered a nuisance that the first train is delayed, since it results in the passenger arriving too late to his or her final destination. The problem is that the delay is divided into different time elements; *prolonged driving time* and *prolonged waiting time*, as illustrated below:

Time element	Driving time, train X		Driving time, train Y		Total driving time		Waiting time		Total trip time
Scheduled driving time	10 min	+	10 min	=	20 min	+	5 min	=	25 min
Realized driving time	16 min	+	10 min	=	26 min	+	9 min	=	35 min
Difference	6 min	+	0 min	=	6 min	+	4 min	=	10 min

Table 3: *Delay occurs in two different ways; prolonged driving time and prolonged waiting time.*

The problem here is how to incorporate the experienced delays in a socio-economic analysis? Is it safe to assume that the nuisances of the two delays are equal? Or is it a more realistic assumption that one type of delay is more of a nuisance than the other? In this specific example; should the prolonged waiting time be equal to the double VOT for waiting time (since delay time is twice as high as driving time according to table 1)?

Finally imagine that a passenger catches a delayed train (and therefore depart from a given station before planned). This will result in the passenger arriving before planned – a so-called "*negative delay*" – at his or her final destination as illustrated below. Note that a passenger can be on time (or before time) even if a train is delayed.

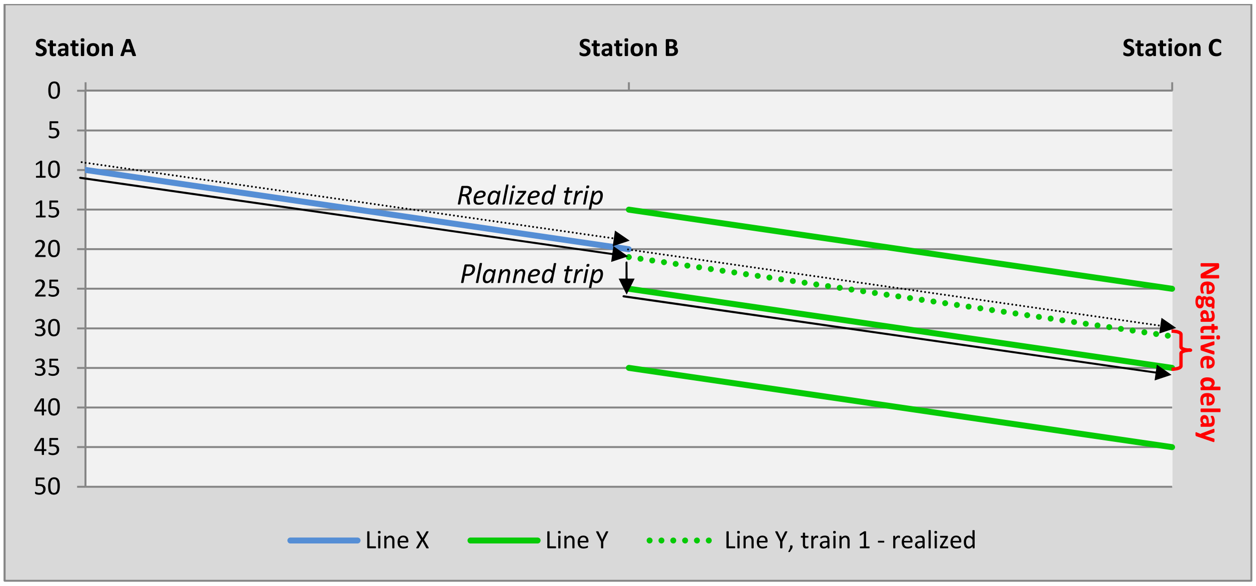

Figure 4: *Example of a negative delay.*

Should a negative delay count as a socio-economic gain or is time gained from negative delays "unusable" for the passenger and therefore insignificant? In reality it depends on each and every one of the passengers and what type of activity he or she should participate in afterwards. Passengers with flexible work hours or passengers who are simply heading home will benefit of arriving earlier than planned, while passengers attending an activity with a fixed starting time (sports training, work at shops, etc.) might not benefit from an earlier arrival time, since they are not able to use the extra time gained. On the other hand it could be that if the time gained exceeds a specific threshold enables them to use the gained time in some way, making only minor *negative delays* unusable.

All in all, the questions and problems listed above are very subjective and vary from passenger to passenger making it extremely difficult to find a general calculation method that satisfies all passengers. The next chapter describes some paradoxes which can occur depending on the chosen calculation method.

Potential paradoxes

Depending on how the socio-economic value of the realized trip is calculated paradoxes can occur. Assume a planned trip with 3 minutes of first waiting time and 10 minutes of driving time between station A and station B (same as table 2). According to table 1 the socio-economic value of that trip will be:

$$Socio\ economic\ value = 3\ min \cdot \frac{185{,}19}{60} DKK/min + 10\ min \cdot \frac{92{,}60}{60} DKK/min = 24{,}69\ DKK$$

Assume that the train is 1 minute delayed at station A, but is on time upon arrival at station B. The overall time of the passenger's trip is identical with the planned trip, although the passenger has experienced a delay during the trip. The passengers are at their final destination on time and are therefore not prevented from attending any activity that they might have planned. However if the realized times are used in order to calculate the socio-economic cost of the trip a different value occurs even though the passenger is on time:

$$Socio\ economic\ value = 4\ min \cdot \frac{185,19}{60} DKK/min + 9\ min \cdot \frac{92,60}{60} DKK/min = 27,78\ DKK$$

Note that the same trip between the exact same stations has two difference socio-economic values even though the trip has the same overall duration. Depending on the situation the example above can also occur in the opposite direction where a realized trip is priced lower than the planned trip, even though the overall time spent on the trip is identical. All in all three types of paradoxes can occur:

Paradox 1: A realized trip with the same overall duration as the planned trip is priced higher or lower (than the planned trip) in a socio-economic analysis.

Paradox 2: A realized trip that is faster overall than the planned trip is priced higher in a socio-economic analysis.

Paradox 3: A realized trip that is slower overall than the planned trip is lower higher in a socio-economic analysis.

The next chapter describes the recommendations of how to estimate the socio-economic values of passenger trips in order to avoid “paradoxes”.

Recommendations of this article

This chapter lists the recommendations of this article on how to define delays as well as the VOT for delays. This article recommends to define a delay solely from the difference between a passengers planned and realized arrival time to his or her final destination, since the real nuisance must be whether or not the passenger is on time or not. Based on this assumption a trip will be priced according to the passengers planned trip (travel time and -pattern) plus the delay itself (which will be calculated as the difference between the planned and realized arrival time).This means that a delay during the trip will only be included in the socio-economic analysis if it result in the passenger arriving later than planned at his or her final destination. One of the main arguments for this recommendation is to avoid potential paradoxes that might occur with other ways of defining delays and the value of time. Based on this definition a passenger can experience one of the following four events:

(1) The passenger arrives on time to his or her final destination.
(2) The passenger arrives too late (according to the planned arrival time) to the final destination.
(3) The passenger arrives before planned (a so-called negative delay).
(4) The passenger cannot complete the planned trip[2].

[2] This can for example happen if a train gets cancelled or the passenger misses a transfer (and there are no trains departing later). This phenomenon is fairly seldom however.

AD1: If the passenger is on time to his or her final destination the trip will be priced solely from the planned trip, even if the passenger has experienced delays during the trip or have taken another route[3]. The planned trip for *passenger i* will be calculated from the planned timetable (the output from "calculation 2" on page 3) as:

$$Socio\ economic\ value, scheduled\ trip_{pass.\ i} = driving\ t_{pass.i} \cdot unit\ price_{driving\ t} + waiting\ t_{pass.i} \cdot unit\ price_{waiting\ t} + first\ waiting\ t_{pass.i} \cdot unit\ price_{first\ waiting\ t} + hidden\ waiting\ t_{pass.i} \cdot unit\ price_{hidden\ waiting\ t}$$ **(Formula 1)**

AD2: If the passenger is too late at his or her final destination the trip is priced as the socio-economic value of the planned trip as calculated in formula 1 plus the socio economic value of the delay. The delay will be priced according to the VOT of delays by *Modelcenteret*, see table 1, no matter how or why the delay has occurred.

AD3: If the passenger arrives before planned the trip is priced as the socio-economic value of the planned trip as calculated in formula 1 minus the socio-economic value of the *negative delay*. This article recommends using a unit price equivalent to *hidden waiting time* as the VOT for *negative delays*, see table 1. The argument for using the same unit price for negative delay as hidden waiting time is that some trips can be considered as having waiting time similar to *hidden waiting time* at the end of the journey[4]. Therefore the VOT for *negative delays* can be assumed to be equivalent to the VOT of *hidden waiting time* in lack of a better estimate. The weighting of *hidden waiting time* is 0,8 compared to driving time (see table 1) which is adequate since not all passengers are able to utilize the time gained from a *negative delay*. Overall a *negative delay* is considered a gain in the socio-economic analysis since the trip all in all is shorter than planned. Based on the recommendations above the socio-economic value will be calculated as[5]:

$$Socio\ economic\ value = \sum_{i=1}^{I} \left[Socio\ economic\ value, scheduled\ trip_{pass.\ i} + \left(RAT_{pass.\ i} - SAT_{pass.\ i}\right) \cdot unit\ price\right]$$ **(Formula 2)**

The *unit price* will vary depending on whether the passengers arrive too late or too early:

- If $Realized\ arrival\ time > Planned\ arrival\ time \rightarrow unit\ price_{delay}$
- If $Realized\ arrival\ time < Planned\ arrival\ time \rightarrow unit\ price_{hidden\ waiting\ time}$
- If $Realized\ arrival\ time = Planned\ arrival\ time \rightarrow unit\ price$ not necessary

AD4: In case of (4) where a passenger is not able to complete his or her trip in the realized timetable a nuisance value of the prevented trip must be estimated. This can be done in different ways, but this article proposes a method consisting of scaling factors based on the planned trip – the trip which the passenger had planned but was not able to conduct. The nuisance of a prevented trip must depend on different factors:

[3] The reason for this calculation method is in order to avoid paradoxes as described in this article.
[4] Assume a passenger arriving at work 8:57 and have a meeting 9:00. That passenger will in theory have a "hidden waiting time" at the end of the journey similar to the hidden waiting time in the beginning of the trip.
[5] Abbreviations in equation are as follows: *SAT = Scheduled Arrival Time*, *RAT = Realized Arrival Time*.

- The length of the trip: The length of the trip must affect the nuisance in case of a cancellation, since it is more difficult to find alternatives for longer trips.
- The purpose of the trip: This is implicit taken into consideration in the socio-economic value of the planned trip.
- The departure time of the trip: The nuisance of a cancelled trip must depend on the time of day, since it is harder to find alternatives to a cancelled train during the night, than during the day due to the lower frequency during the night (if any at all).
- The geographical location of the trip: The nuisance of a cancelled trip must also depend on the geographical location of the trip, since it is easier to find alternatives to a cancelled train in certain locations than others, e.g. city centers, major transport hubs, etc.
- Immediately nuisance when the passenger realize that the trip cannot be completed: This nuisance can be seen as a startup nuisance the passenger experience when he or she realizes that e.g. a train is cancelled[6]. In this article the startup nuisance is set equal to a change penalty, see table 1, since a cancelled train or a prevented trip forces the passenger to (mentally) change route and/or mode (even though the passenger may never have boarded the cancelled train).

This article proposes to calculate the nuisance of an incomplete trip under "optimum condition" as:

$$Nuisance, \text{"}opt.condition\text{"}_{pass.i} = startup\ nuisance + Socio\ economic\ value, planned\ trip_{pass.i} \cdot factor_{length\ of\ trip}$$ (Formula 3)

Where the startup nuisance is equivalent to the *change penalty* and the scaling factor is set to 2 in this project[7], making an incomplete trip twice as costly as the planned trip. The socio-economic value of the planned trip is calculated as done in formula 1. The nuisance under *"optimum condition"* is assumed to have the best possible alternatives to a cancelled train or a prevented trip. In order to take into consideration that not all prevented trips occurs under "optimum conditions" some scaling factors are introduced in order to account for time of day as well as geographical locations. A scaling factor of 1 indicates that the prevented trip has occurred under "optimum conditions" as reasonable alternatives were present. This article recommends scaling factors between 1-2[8] and proposes to calculate the nuisance for incomplete trips as follows:

$$Nuisance, incomplete\ trip = \sum_{i=1}^{I} Nuisance, \text{"}opt.condition\text{"}_{pass.i} \cdot factor_{time\ of\ day\ of\ pass.i's\ trip} \cdot factor_{geographical\ \ location\ of\ pass\ i's\ trip}$$ (Formula 4)

The scaling factors must be defined from project to project. An example of scaling factors could be the suburban railway network in the greater Copenhagen region listed below:

---

[6] Note that a cancelled train will only count as an incompleted trip if there are no trains departing later. If there are later departing trains the trip will be considered as completed but with a delay equivalent to the time difference between the two trains.

[7] The argument for this is that delays are weighted twice as high as driving time, see table 1.

[8] Yet again the argument for having 2 as the upper boundary is due to the weighting of delays with the value 2, see table 1.

Geographical location	Scalingfactor	Time of day	Scalingfactor
Stations within *Ringbanen*	1	Peak hours	1
Stations along *Ringbanen*	1½	Day hours	1½
Stations outside *Ringbanen*	2	Evening, night and early morning	2

Table 4: *Assumed scaling factors in case of incompleted trips for the suburban railway network in greater Copenhagen.*

Estimation of the socio-economic value of cancelled or incompleted trips is a relatively unresearched area which could need further investigation. However cancelled or incomplete trips will only contribute to a few percent of the total socio-economic value since this happens very seldom.

All in all (the output from) the passenger delay model can be used in a socio-economic cost-benefit analysis in order to include delays in the analysis. The article "*Optimization of timetable supplement from a passenger based socio-economic point of view*" (Thorhauge, 2010) discusses how the method described above can be used to optimize and compare different timetable and infrastructures in a socio-economic analysis.

References

Bagger, P., 1. september 2009, *APS Database beskrivelse v.4.0*, Rapidis.

Frederiksen, R.D. & Brun, B., 2008, *Metode til rutevalg, pessimistisk opgørelse*, Rapidis ApS.

Landex, A. & Nielsen, O.A., 2006, *Simulering af passagerforsinkelser på jernbaner*, Center for Trafik og Transport (CTT), Danmarks Tekniske Universitet (DTU), Trafikdage på Aalborg Universitet.

Modelcenter, (August) 2009, *Transportøkonomiske Enhedspriser - til brug for samfundsøkonomiske analyser*, Udarbejdet af DTU Transport og COWI for Transportministeriet.

Seest, E., Nielsen, O.A. & Frederiksen, R.D., 2005, *Opgørelse af passagerregularitet i S-tog*, DSB S-tog, Centrer for Trafik og Transport (CTT), Danmarks Tekniske Universitet (DTU) & Rapidis Aps., Trafikdage på Aalborg Universitet.

Thorhauge, M., (August) 2010, *Optimization of timetable supplement from a passengerbased socio-economic point of view*, Department of Transport (DTU Transport), Technical University of Denmark (DTU), Trafikdage på Aalborg Universitet 2010.

Thorhauge, M. & Piester, M., (28. februar) 2010, *Samfundsøkonomiske fordele i køreplaner ved hjælp af passagerforsinkelsesmodeller*, 2. edition edn, Institut for Transport (DTU Transport), Danmarks Tekniske Universitet (DTU).

Trafikministeriet, (Juni) 2003, *Manual for samfundsøkonomisk analyse - anvendt metode og praksis på transportområdet*.