# The usability of passenger delay models in socio-economic analysis

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## 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 socio economic 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.

When using a passenger delay model, the main problem is how to properly include the delays in a socio-economic analysis. This is due to the fact that passenger delays are not necessarily 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).

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, delays, 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) the level of details will improve in the overall cost-benefit analysis. Furthermore the passenger delays can be used to predict delays in a given timetable, and thereby optimize the timetable supplement making the overall public transportation network more coherent. This is described further in (Thorhauge, 2010).

## 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 (more traditional route choice) models is that the third generation passenger delay model calculates the route choice in a two step process;

- Step 1: Calculate the route choice based on the scheduled timetables (in order to minimize the "cost" of the trip[1]) – this will determine which route the passenger will use in an ideal situation where no delays occur (the passengers "the planned route"). This step is similar to a traditional schedule based route choice model, where as the next step is exclusive for the passenger delay model. After the route choice assignment has been conducted information about the passengers' routes are stored as a sequence of stations along the routes[2].
- Step 2: In step 2 the passenger delay model will assign passengers along the stored routes from step 1 using the first departure in the realized timetable between the stored sequences from step 1[3] – this will estimate the travel time in case of delays. In this way the passenger delay model assumes that a passenger will not have knowledge of future delays, hence the passenger will not be able to plan according to unknown future events that may affect the realized timetable. If the passenger get delayed beyond a certain threshold (or for some reason is unable to complete his or her journey along the stored route)

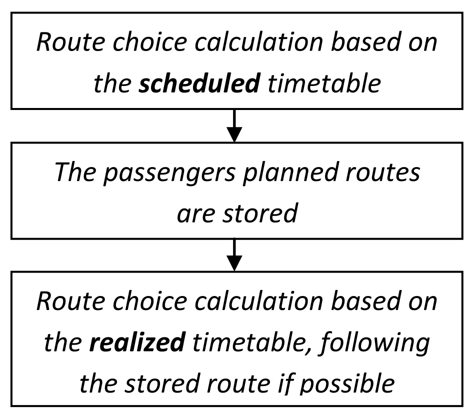


**Figure 1:** *Principle of the third generation passenger delay model. Based on* (Landex & Nielsen, 2006).

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

[2] Assume a trip from station X to station Y with a transfer in station Z. In this case the following sequences are stored; sequence X to Z, and sequence Z to Y.

[3] In the example of footnote 2, the first train between X and Z will be used, and thereafter the first train between Z and Y will be used. Note that the model has some modeling restrictions to ensure that the passenger begin his or her journey around the planned departure time of the first train.

the passenger delay model will recalculate the route choice from that point in space and time using only the realized timetables.[4]

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, 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). Afterwards the passenger delay model recalculates the passengers trip (stored from step 1) using the realized timetable. In addition it is important to note that the passenger delay model does not calculate the delays, but calculate the travel time/pattern in case of delays[5]. For further information about the passenger delay model see (Frederiksen & Brun, 2008), (Bagger, 2009), (Seest, Nielsen & Frederiksen, 2005) and (Landex & Nielsen, 2006).

## How to properly include the delays in a socio-economic analysis based

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 properly include the delays. 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[6].

When including delays in a socio-economic analysis, there are different way of doing so, and delays as such might not always by unambiguous definable, as illustrated by the examples listed on page 4-6. (Fosgerau et al., 2008) propose a method to include delays in a socio-economic analysis based on the mean and standard deviation of the travel time. The method proposed by (Fosgerau et al., 2008) has the advantage that it is applicable with current traditional traffic models which does not directly model delays[7]. This method is, however, not directly transferable to this case, since the passenger delay model does explicitly model the passenger delays. With this information it is possible to include delays in a socio-economic analysis, based on the actual passenger delays. The Value of Travel Time, VTT, published by (Modelcenter, 2009) are shown below and forms the base of the methods proposed by (Fosgerau et al., 2008) as well as in this article:

[4] This way the model reflects the behavior that a passenger may (and most likely will) react in case delays exceed a certain threshold.

[5] 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 times in the two scenarios must be considered as the delay (note that a delay can also be negative). In practice this means that it's necessary to run the passenger delay model twice; Once with delays (where the realized timetable is used, and once without delays, where the realized timetable is not used.

[6] 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.

[7] E.g. Traffic Analyst by Rapidis.

| 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 |
| Waiting time | 2 | 158,07 | 665,99 | 158,07 | 185,19 |
| First waiting time | 2 | 158,07 | 665,99 | 158,07 | 185,19 |
| Hidden waiting time | 0,8 | 63,23 | 266,40 | 63,23 | 74,08 |
| Changing time | 1,5 | 118,55 | 499,49 | 118,55 | 138,89 |
| Change penalty (DKK per change) | - | 7,90 | 33,30 | 7,90 | 9,26 |

**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:

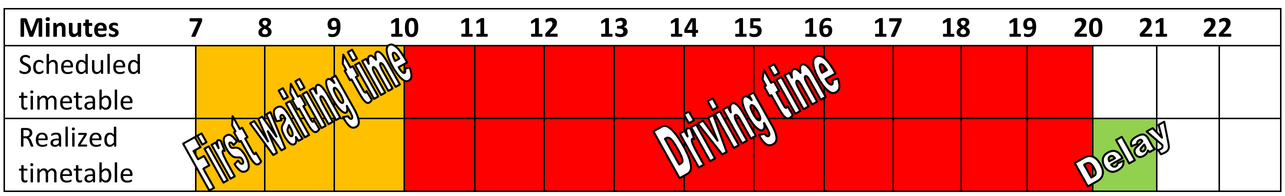


**Table 2:** *Example of a situation where delays can be uniquely defined as prolonged driving time.*

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, given the detailed information available from the passenger delay models, more complex situations will give rise to different ways of implementing the VTT’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 in Figure 2.

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.

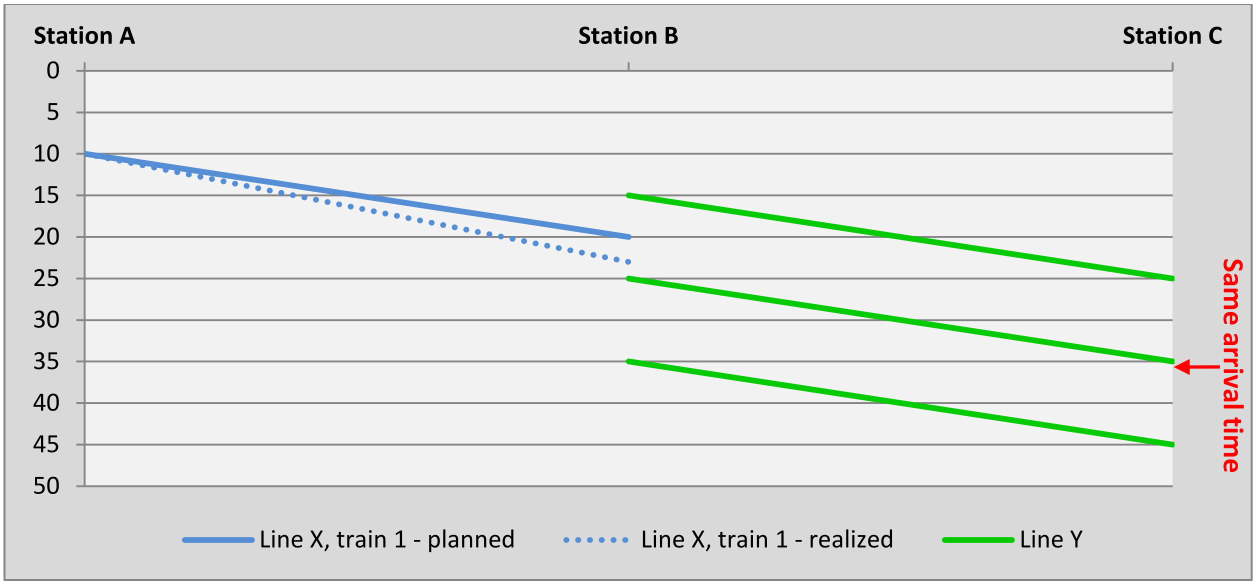


**Figure 2:** *Example of a delay which can be considered negligible.*

The problem in this example 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 included 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:

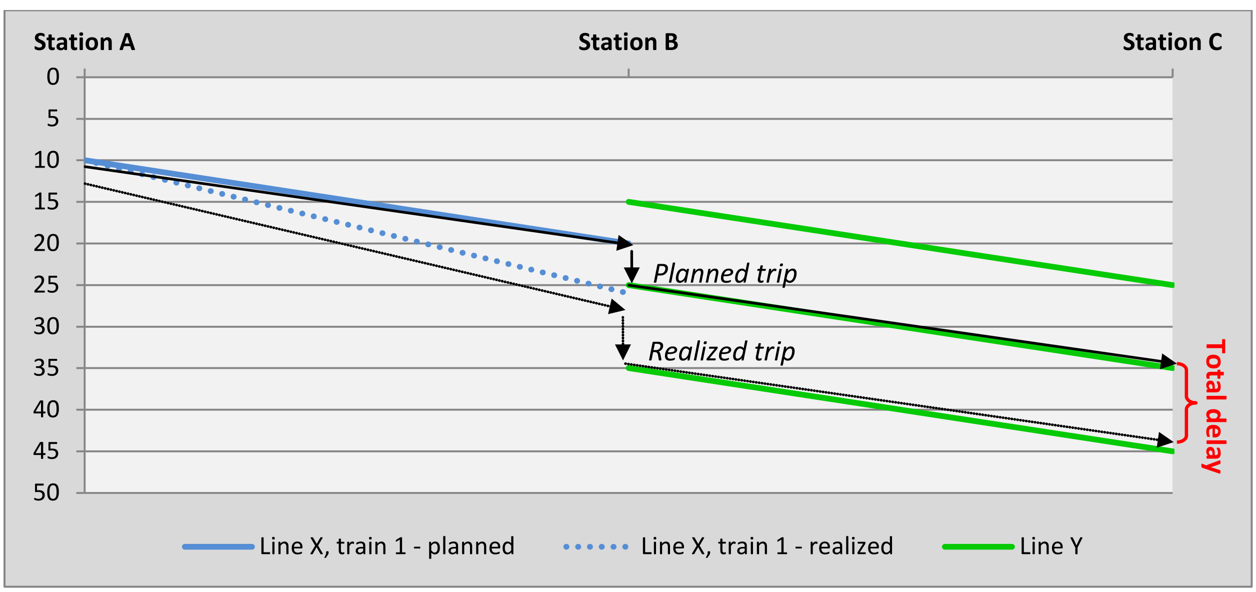


**Figure 3:** *Example of a delay which occurs a different time elements; prolonged driving time and prolonged waiting time.*

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 in this example 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 VTT 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[8] at station B). This will result in the passenger arriving before planned – a so-called "*negative delay*" – at his or her final destination as illustrated below.

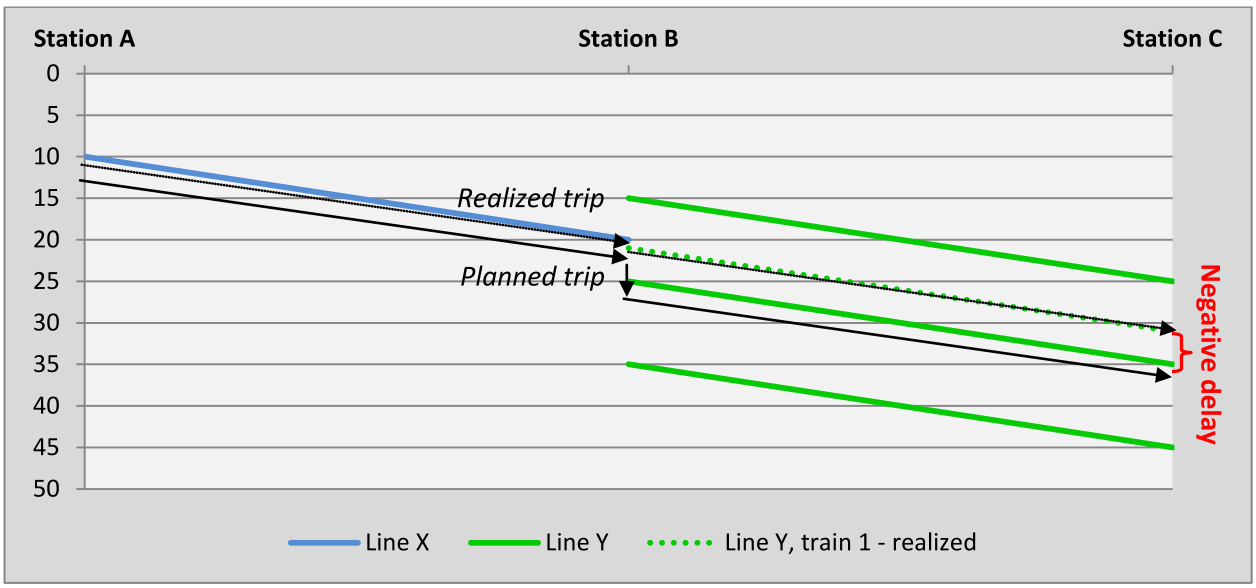


**Figure 4:** *Example of a negative delay.*

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 from 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.

[8] Which is possible with the passenger delay model, since the model allows the passenger to take the first train departing from a given station between sequence i → i+1. Note that a passenger can be on time (or before time) even if a train is delayed.

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, when conducting a socio-economic analysis based on the passenger delay model.

## Potential paradoxes

Three types of paradoxes can occur when including delays in socio-economic analysis[9]. 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 duration of the passenger's trip is identical with the planned trip, although the passenger has experienced a delay during the journey. 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 at his or her final destination:

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

Note that the same trip between the exact same stations has two different 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 (as the example above).
- **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 priced higher in a socio-economic analysis.

The next chapter describes the recommendations of how to estimate the socio-economic values of passenger trips based on a passenger delay model in order to avoid "paradoxes".

## Recommendations of this article

This section lists the recommendations of this article on how include delays in a socio-economic analysis based on a passenger delay model. 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

[9] Depending on how the socio-economic value is calculated.

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 as described above. Based on this definition a passenger can experience one of the following four events listed on page 3.

***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[10]. The planned trip for *passenger i* will be calculated from the planned timetable 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 VTT 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 VTT 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[11]. Therefore the VTT for *negative delays* can be assumed to be equivalent to the VTT 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[12]:

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

[10] The reason for this calculation method is in order to avoid paradoxes as described in this article.

[11] 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.

[12] Abbreviations in equation are as follows: *SAT = Scheduled Arrival Time*, *RAT = Realized Arrival Time*.

***AD4:*** In case 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. On one hand one might argue that an incomplete trip simply should be treated as a delay until the trip can be conducted (in most cases the following day), making case 4 a modeling problem. On the other hand, however, some trips will not be conducted the following day, since the planned activity will only happen that specific day (e.g. concerts, weddings, and similar onetime events). In these cases an incomplete trip, will not be conducted later on, and must be regarded as a cancelled trip.

In addition, it is reasonable to assume that the VTT for delays change when there is a shift from short term delays to long term delays (or in other words; postponed trips), since people are able to utilize long delays better than short delays[13]. Therefore it seems reasonable to distinguish between trips that cannot be completed (at least not at the moment), and trips which merely experience delays.

In this case, due to the fact that modeling is restricted to 24 hours period for practical reasons, the exact duration (and the utilization for that matter) of the long term delay are not modeled. Therefore in order to somehow capture the effect of incomplete trips (although they might be conducted the following day) and the nuisance thereof, a method is proposed.

The nuisance of a prevented trip must depend on different factors: e.g. time of day, geographical location (alternative routes), length of the trip, etc. This article proposes to calculate the nuisance of an incomplete trip under "optimum condition" as:

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

Where the *startup nuisance* is equivalent to the *change penalty* and the scaling factor is set to 2 in this project[14], making an incomplete trip twice as costly as the planned trip (plus the *startup cost*). The socio-economic value of the planned trip is calculated as done in formula 1. 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. This article recommends scaling factors between 1-2[15] and proposes to calculate the nuisance for incomplete trips as follows:

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

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 in Table 4. 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.

[13] In case of long term delays the passengers can go home, working or (if the delay occurs overnight) sleep.
[14] The argument for this is that delays are weighted twice as high as driving time, see table 1.
[15] 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, while a scaling factor of 1 will indicate that nuisance is unchanged compared with "optimum condition".

| 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.*

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 in this paper can be used to optimize and compare different timetable and infrastructure projects in a socio-economic analysis.

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