The value of enhanced service reliability

Case study: transformation from bus to light rail

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Abstract

Service reliability is an important quality characteristic in public transport. However, in cost-benefit analyses (CBA), this quality aspect is rarely taken into account explicitly. It is more common to calculate vehicle indicators (e.g. punctuality) instead of passenger focused metrics. In this paper, we demonstrate how to calculate the passenger impacts of service unreliability. In an actual case, the replacement of a bus line by a light rail line in Utrecht, we proved that our method is valuable and can be applied directly into practice. By calculating the benefits of the improved service reliability of the proposed light rail line, which were about 2/3 of all benefits, the cost benefit ratio was positive, which convinced the Dutch Minister of Infrastructure and Environment to support the project by €110 million.

1 Introduction

Service reliability is an important quality characteristic in public transport. However, in cost-benefit analyses (CBA, see for instance [2,11] for more details), this quality aspect is rarely taken into account explicitly. It is more common to calculate vehicle indicators (e.g. punctuality) instead of passenger focused metrics. In a CBA however, the latter is required to illustrate the potential benefits of a project [12]. Figure 1 shows the results of a quick scan of randomly selected public transport projects in the Netherlands. It is demonstrated that the attention to calculating service reliability effects is limited. Most of the time, a qualitative assessment or expert judgement is used, while proper calculations would be more appropriate since most public transport projects aim at improving service reliability. In our research [26], we presented the main impacts of vehicle variability on passengers, being additional waiting time, a distribution of passenger travel time and crowding.

In this paper, we present a method to calculate these effects and to incorporate them into a cost benefit analysis. Recent research [26] enables proper analysis of service reliability with regard to passengers. The headlines of this method are presented in this paper and in addition, a case study is presented, in which the method is applied. The case study consists of a project of a new light rail line in the city of Utrecht (over 300.000 inhabitants) in the centre of The Netherlands. This light rail line connects the central station in Utrecht with the university and the hospital. To provide a proper alternative to car traffic, high quality of service is necessary. High service reliability is one of the main objectives in this project.

The case demonstrates that service reliability may be a substantial benefit of a public transport project and in addition it shows the possibilities of incorporating service reliability effects effectively in a CBA. This project successfully connects the results of a PhD research [26] to a practical project, namely the light rail project in Utrecht. This project is a first step to harmonizing standards in CBAs concerning service reliability effects.

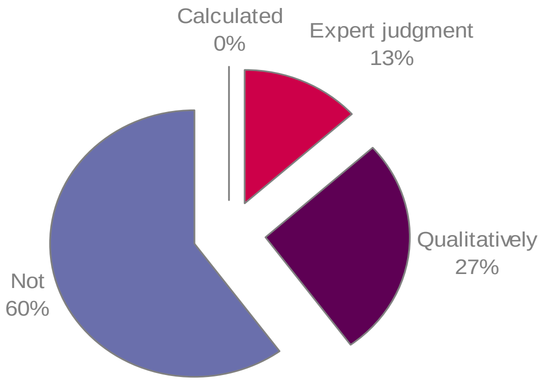

Figure 1: Results of quick scan service reliability in CBA

2 Passenger impacts of service reliability

2.1 Service reliability

We defined service reliability as the certainty of service aspects compared to the schedule (such as travel time (including waiting), arrival time and seat availability) as perceived by the user. Service variability is defined as the distribution of output values of the supply side of public transport, such as vehicle trip time, vehicle departure time and headways. In our research, we mainly focus on the travel time impacts. Service reliability is one of the main quality aspects of public transport and is often at a poor level. Improved service reliability increases the overall quality of public transport, thereby ensuring accessible and liveable cities for future generations and reducing the growth of car mobility [26].

In literature, much research is available with regard to passenger choices as a function of service reliability. In [3,18] it is stated that service reliability of public transport systems has been considered critically important by most public transport users because passengers are adversely affected by the consequences associated with unreliability such as additional waiting time, late or early arrival at destinations and missed connections, which increases their anxiety and discomfort. Route choice might be affected by unreliability, as presented by [1,13,19]. Service reliability is also been identified as important in determining the mode choice [21]. Therefore, it may be stated that unreliability in public transport drives away existing and prospective passengers.

Reversely formulated, enhanced reliability will attract more public transport users. Research [28] shows that people are likely to change their mode of transport because of changes in the level of service reliability.

2.2 Impacts of service unreliability

In preparation of quantifying service reliability, this section demonstrates the impacts of service reliability on passengers. The passenger mainly experiences the following three effects [14,15, 26]. Note that due to the stochastic nature, the impacts on individual passengers may differ from average values.

- Impacts on duration of travel time components, being in-vehicle time and waiting time, which lead to arriving early or late;
- Impacts on variability of travel time components, being departure time, arrival time, in-vehicle time and waiting time, which lead to uncertainty of the actual travel time;
- Impact on probability of finding a seat and crowding, which affects the level of comfort of the journey.

This paper focuses on the first two aspects, namely the travel time related aspects.

To calculate the passenger effects of unreliability it is important to gain insights into the quality of service of public transport operations.

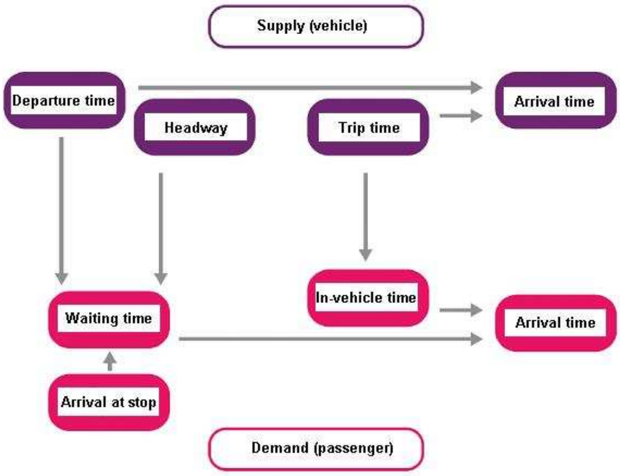

Figure 2: (Interaction of) Components on demand and supply sides

This consists of characteristics of the service supply, such as actual departure times per stop, actual dwell times, actual headways and actual trip times. In the calculation of service reliability effects, this vehicle related data (available by Automated Vehicle Location (AVL)-systems) is translated into passenger effects, using Automated Passenger Counter (APC) data. Figure 2 illustrates the differences and relations between the demand and supply sides. Vehicles leave the stop at a departure time and with a time interval between its predecessor. Depending on the passenger arrival time, this affects the passenger waiting time. If the passenger arrives at random, the headway between successive vehicles determines the waiting time. When the passenger arrives in conformance with the scheduled departure time, the deviation of the schedule affects the waiting time. For example, if the vehicle departs ahead of schedule, passengers will have to wait a full headway.

The successive part of the trip is the driving itself. In this phase, the passenger time aspects are similar to these of the vehicle. In this paper, we provide equations to translate vehicle characteristics into passenger effects. This relationship depends on the arrival pattern of passengers at their arrival stop. In this paper, we only investigate high frequent systems. In a survey [26] we concluded that passengers tend to arrive at random if headways are 10 minutes or less. In that case the additional waiting time of passengers is determined by the headway variation.

The main conclusion is thus that service reliability effects on passengers are affected by both vehicle and passenger related aspects. The next section will present a framework that supports calculating these effects.

2.3 Calculating passenger impacts of service reliability

In order to improve service reliability it is essential to monitor and predict the level of service reliability of a public transport system. For this we need proper indicators. The commonly used indicators which are supposed to express reliability do not completely focus on service reliability concerning passenger impacts. In fact, they focus more on service variability of the system than on the actual impacts on passengers. Well known examples of supply side indicators are punctuality and regularity [26]. However, the previous demonstrated the importance of taking the demand side into account while assessing service reliability. The impacts on passengers are mainly measured by customer surveys, which implies only a qualitative assessment. This section introduces a new indicator enabling enhanced quantifying of service reliability. This new indicator is the basis for quantifying service reliability effects in a CBA.

Although the supply-side indicators often help to illustrate the level of service provided to the passenger, they do not completely match the customer perception. Driving ahead or being late for example are completely different phenomena for passengers. The arrival pattern of passengers at the stop where they depart is of importance to determine the impacts for the passenger. If passengers arrive at random, the deviation from the schedule is not relevant anymore. Passenger waiting time is then minimized if actual headways are constant. If passengers use the schedule to plan their moment of arrival at their departure stop, the deviation from the timetable is important.

Service variability may lead to an extension of passenger average travel time, since average waiting time per passenger may be extended due to irregular, early or late vehicles. To express this effect of service variability on passengers more effectively than punctuality and regularity, we introduced a new indicator, called average additional travel time per passenger [25], which expresses the additional time a passenger needs for a trip compared to the schedule.

Using the average additional travel time per passenger as an unreliability impact indicator, the focus on quantifying service reliability shifts from the supply side (variability) to the impacts on the demand side. Using this indicator, increase or decrease of average total travel time due to changes in service variability may be properly expressed, enabling analyses of introducing new instruments and comparing several network designs and timetable proposals in for instance cost-benefit analyses. At this moment, proper expressing of passenger reliability benefits is hardly possible [20]. The additional travel time indicator also enables to deal properly with the trade-off between speed and service reliability (as also discussed by [7]). Using supply oriented indicators would lead to a focus on the match between schedule and operations which might lead to suboptimal timetables. For instance, the timetable is the reference indicating the match and decreasing the speed in the timetable might improve this match. As schedules (and operations) might become slow, it is obvious that this will not necessarily lead to an increase in overall service quality.

Additional travel time is not commonly used in both theory and practice. An international survey [24] showed that only London seems to use a comparable indicator: excess journey time [6, 22]. This indicator also expresses the additional travel time due to unreliability, but it compares actual and free-flow travel times instead of actual and scheduled travel times.

When calculating the additional travel time, two situations have to be distinguished, namely planned or random arrivals of passengers at the stop. If passengers arrive at random, exact departure times are not relevant anymore, neither is punctuality. In general, passengers do not use any schedule anymore. Sometimes, operators do not even provide departure times; they just show the headway during different time periods. This paper continues describing additional travel time regarding random arrival patterns. More research on scheduled arrival patterns is available in [27]. Main assumptions in the calculations are:

- The examined period is homogeneous concerning scheduled departure times, trip times and headways (for instance rush-hour on working days in a month);
- The passenger pattern on the line is assumed to be fixed;
- All passengers are able to board to the first arriving vehicle.

If passengers arrive at the stop at random, the additional travel time is calculated using the coefficient of variation (CoV) of the actual headways ($\tilde{H}_{l,j}^{act}$). A generic formulation for the expected waiting time per passenger is given by Equation 1 [10,16,29], given the assumptions mentioned above.

$$E(\tilde{T}_{l,j}^{waiting}) = \frac{E(\tilde{H}_{l,j}^{act})}{2} * (1 + CoV^2(\tilde{H}_{l,j}^{act})) \tag{1}$$

where:

$\tilde{T}_{l,j}^{waiting}$ = passenger waiting time at stop j on line l

$\tilde{H}_{l,j}^{act}$ = actual headway of line l at stop j

$CoV(\tilde{H}_{l,j}^{act})$ = *coefficient of variation of actual headways of line l at stop j*

If the service is regular, the covariance equals zero and the average waiting time will be equal to half the headway. In the case of irregular service, the additional waiting time may then be calculated using Equation 2. Assuming no change in the actual vehicle trip times, the total average additional travel time per passenger will be equal to the average additional waiting time per passenger.

$$E(\tilde{T}_{l,j}^{Add,waiting}) = \frac{E(\tilde{H}_{l,j}^{act})}{2} * (CoV^2(\tilde{H}_{l,j}^{act})) \tag{2}$$

where:

$E(\tilde{T}_{l,j}^{Add,waiting})$ = *average additional waiting time per passenger due to unreliability of line l at stop j*

Based on the average additional travel time per passenger per stop of a line, we may calculate the average additional travel time per passenger on the complete line. To do this, the proportion or percentage of boarding passengers per stop is used ($\alpha_{l,j}$), as shown by Equation 3. Please note that using the proportion of passengers makes the indicator independent of the actual number of passengers.

$$E(\tilde{T}_l^{Add,waiting}) = \sum_j (\alpha_{l,j} * E(\tilde{T}_{l,j}^{Add,waiting})) \qquad with \qquad \sum_j \alpha_{l,j} = 1 \qquad (3)$$

where:

$\alpha_{l,j}$ = *proportion of passengers of line l boarding at stop j*

When $E(\tilde{T}_l^{Add,waiting})$ and its distribution are calculated, using both vehicle and passenger data, the next step is to express these values in money to incorporate them into a CBA. This will be presented by the next section.

2.4 Incorporating service reliability effects in cost benefit analyses

Service reliability effects are seldom explicitly taken into account in public transport projects. In road traffic, this issue is discussed in [20] as well and the authors state that the method to deal with this in road traffic projects in the Netherlands (i.e. travel time variability gains are assumed to be 25% of the travel time gains) is an underestimation and is very project specific. One of the main reasons to neglect these effects is that it is complex to calculate them and much data is needed. However, since [26] provided a method to calculate the unreliability effects for passengers, it is only little effort to consider them in a CBA.

The previous section demonstrated how to calculate the passenger effects of service unreliability, namely the additional travel time per passenger and its distribution. Both effects imply disbenefits for both existing and new passengers. In [17] it is stated that passengers value one minute standard deviation of travel time 40% higher than a minute of regular travel time.

Table 1 shows both the value of time and value of reliability as used in The Netherlands in 2011. Note that these numbers depend on many factors, such as motive, year and transport mode.

Table 1: Value of time and value of reliability in 2011 [5]

Travel purpose	**Value of time**	**Value of reliability**
Business	€ 10.00	€ 14.00
Commuter	€ 17.44	€ 24.42
Other	€ 6.33	€ 8.86

To incorporate the service reliability effects in a CBA, the effects calculated using the equations presented in section 2.3 should be combined by the values shown by table 1. In this step, the relative weights of different travel time components (e.g. waiting time vs. in-vehicle time) may be incorporated (see for instance [23]). In the next section a case study will presented, where this method has been successfully applied.

3 Case study light rail project "Uithoflijn"

3.1 Introduction

In addition to the setting up a theoretical framework, we also performed a case study in the city of Utrecht in The Netherlands. Utrecht is the fourth largest city in The Netherlands with over 300,000 inhabitants. The Dutch government required a cost benefit analysis to financially support the construction of a new light rail line in Utrecht between the central station and the Uithof, where the hospital and university are situated.

At this moment the quality of service of the public transport between Utrecht central station and the Uithof is quite poor. Figure 3 shows the current line, which has a total scheduled trip time of approximately 18 minutes.

Although services are operated by double articulated buses with a scheduled frequency of 23x per hour per direction, passenger capacity is lacking. On a regular basis, passengers have to wait for 2 or three buses to board. Only on small parts of the route, own right of way is provided, which leads to conflicts and hindrance with cars and cyclists. This occurs especially at the border of the old town, where space is limited.

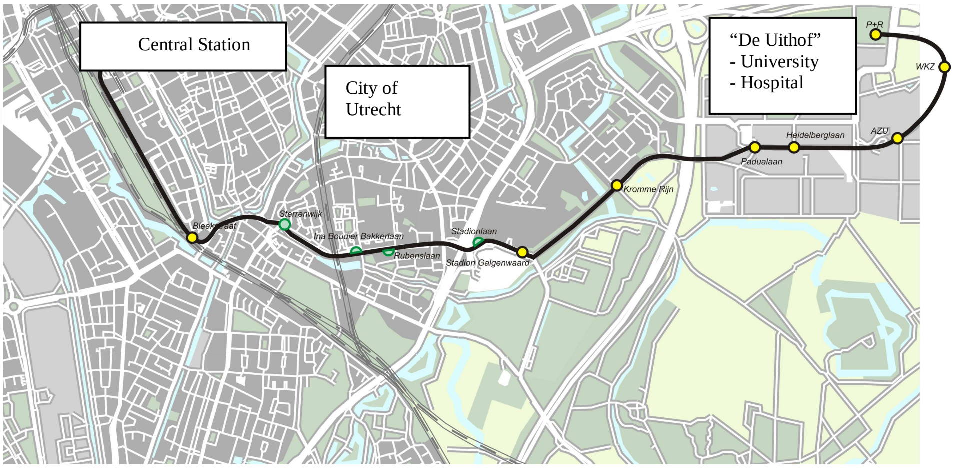

Figure 3: Current route of bus line Central station-Uithof and vv.

Due to the interaction with other traffic, busses are delayed all the time and often bunching of two or even three buses occurs. The hindrance and the large amount of passengers using the service result in very unreliable bus operations. The average deviation of the timetable is 4 minutes and thus exceeds the scheduled headway (about 2.5 minutes). Nowadays, about 30,000 daily passengers use this line, operated by double articulated buses.

The Uithof is situated in the East of Utrecht, a cluster of knowledge, consisting of the University and other schools, the hospital and several related companies. The plans of the city of Utrecht are to expand this area by 25% [8]. In the end, 53,000 students and 30,000 employees among visitors will use this area. Another objective of the city is to handle the growth in mobility by stimulating the usage of bike and public transport. No additional parking lots will be constructed. Demand forecasts [9] show a growth towards 45,000 passengers per day in 2020, which will require over 50 buses an hour per direction to provide adequate capacity. The existing infrastructure is not able to support this number of buses.

To deal with this large leap in public transport use, ensuring high level of service, a new connection is designed. This new line is a fast and reliable connection between the central station and the Uithof. To facilitate reliable service, plans are made to shift from bus to light rail services. This line is called the “Uithoflijn”. Figure 4 shows this line, which is about 8 km long and will operate about 16-20 x per hour per direction during the morning peak.

The main benefit of transferring the bus line into a light rail line is, next to less direct emissions, that service can be provided by fewer vehicles than in the case of bus operations. And since fewer vehicles are needed, the hindrance for crossing traffic (i.e. car and bike traffic) is less, and more importantly, the probability of bunching of vehicles will decrease. Growth of demand is expected to be larger in the light rail case than in the bus case due to the “rail bonus”. In [4] is presented an additional growth of about 5% due to this factor. However, the construction and operation costs of light rail may be higher than bus operations, especially since Utrecht does not have an extensive rail network that is already available. To gain insights into the details of all the pros and cons, a CBA is an adequate instrument, which has been used for this project. The next section will elaborate on the CBA for the Uithoflijn.

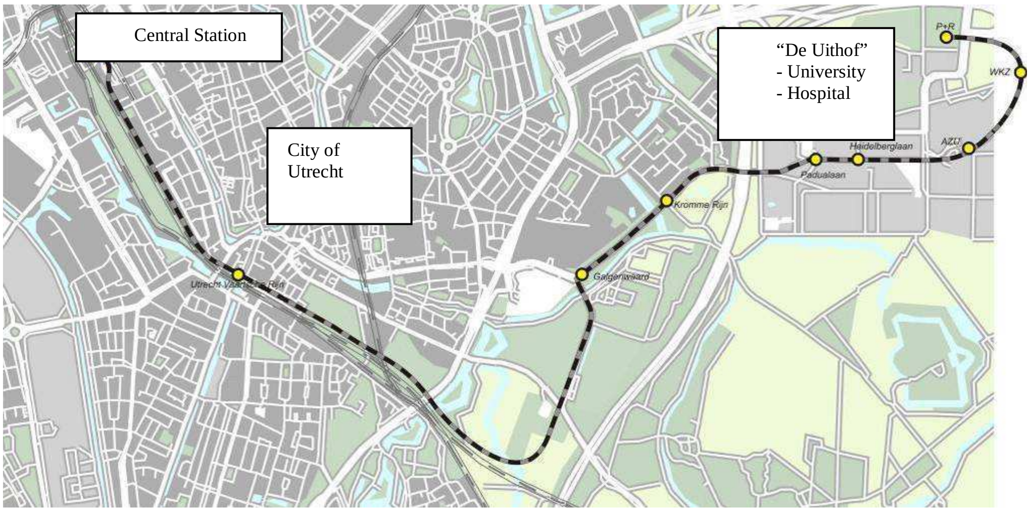

Figure 4: Proposed route of light rail line Central station-Uithof and vv.

3.2 Cost benefit analysis Uithoflijn

To construct the light rail line, the Dutch ministry of Infrastructure and Environment had €110 million available. However, the Minister required a positive CBA (indicating a cost-effective project) before supporting this project [5,9]. In the Netherlands, it is no common use to incorporate service reliability effects in a CBA, since the algorithms were lacking. The expectation however was that the service reliability effects would play a major role in the CBA of the light rail line. And since research concerning service reliability [26] was just available, it was possible to apply the results of the research directly into practice.

In the cost benefit analysis of this case we calculated the service reliability benefits of transferring the existing bus system into a light rail system. We compared 5 future situations (in 2020), but in this paper we will only focus on the reference and the preferred alternative. These two cases are described below:

1 Reference case

No additional infrastructure will be constructed and operations will be similar to the poor operations nowadays (i.e. partly right of way as described in Section 3.1). The capacity of infrastructure is limited and passengers continuously experience substantial unreliability.

2 Light rail case

In this case the service is operated by trams with own right of way operations. Due to sufficient capacity on the track and stops and little interaction with other traffic the expected level of service reliability will be high. In addition, compared to the required number of buses (over 50), the number of vehicles is limited, thereby reducing the probability of bunching and delay propagation.

A description of the other alternatives and their costs and benefits may be found in [5] and [9].

We calculated the passenger effects concerning the reduction of waiting time, distribution of travel time and the increase in the probability of finding a seat. For these calculations we used AVL data of the existing bus services. We calculated the future demand of this connection by using a demand model [9] and simulated the new APC and AVL data, adjusting the dwell times and the level of bunching. The predicted AVL and APC data enabled us to calculate the passenger effects. In the reference case, the level of service will be very low due to high passenger demand and insufficient bus infrastructure. In case of the light rail line, sufficient infrastructure is provided and besides, light rail services require fewer vehicles thereby reducing the probability of bunching. We calculated the additional travel time per passenger and the distribution of travel time as shown in table 2, using the framework of Section 2. Due to the high level of service reliability in the light rail case, the negative passenger effects of unreliability are neglectable.

Table 2: Passenger effects of unreliability of services in reference and light rail case

	Reference case	**Light rail case**
Average additional travel time per passenger due to unreliable services	4.9 min	≈ 0 min
Distribution of travel times (standard deviation)	2.4 min	≈ 0 min

Table 3: Additional costs and benefits of light rail line compared to ref. case

	Value compared to reference case (millions in 2011)
Investment costs	-€222
Operating costs	€66
Total costs	*€288*
Additional ticket revenues	€40
Increased travel time	€67
Service reliability effects	
- Less waiting time	€123
- Reduction in distribution	€78
- Increased probability of finding a seat in the vehicle	€4
External effects (emissions, safety, etc.)	€8
Total benefits	*€336*
Benefits-costs	**+€48**
Benefit cost ratio	**1.2**

After the calculation of these values, the monetary values of these effects were calculated, using values of time and values of reliability as shown by table 1. Table 3 shows the total costs and benefits of the project [5], showing the substantial contribution of improved reliability to the positive score of the cost benefit analysis, which is 1.2 (i.e. the benefits are 20% higher than the costs). The impact of less additional waiting time due to enhanced service reliability of the light rail line is €123 (calculated over the complete life cycle) and the reduction of distribution in travel time results in €78 million less societal costs. So, the total of €336 million project benefits consist of about 2/3 of service reliability related benefits.

Since the CBA result was 1.2, the Dutch Minister of Infrastructure and Environment supported the project by €110 Million. Without the presented framework presented in Section 2, it wasn’t possible to calculate the benefits of enhanced service reliability which proved to be a major part of the total benefits.

4 Conclusions

In this paper we demonstrated how to calculate the passenger impacts of service unreliability. We showed that passengers are affected by longer waiting times, more distributed travel times and a reduced probability of having a seat in the vehicle. In the Netherlands, service reliability is not explicitly incorporated in cost benefit analyses, although improved service reliability is often one of the main contributions of public transport projects. In an actual case, the replacement of a bus line by a light rail line in Utrecht, we proved that our framework concerning calculating benefits of service reliability is valuable and can be applied directly into practice. By calculating the benefits of the improved service reliability of the proposed light rail line, which were about 2/3 of all benefits, the cost benefit ratio was positive, which convinced the Dutch Minister of Infrastructure and Environment to support the project by €110 million.

This paper shows a direct application of a scientific research into practice, thereby closing the gap between science and the practical world. In the case study presented the impacts of quantifying the service reliability were substantial and made the difference between a positive or negative business case.

Although quantifying the effects of service reliability concerning travel time is possible now, further research is still necessary to calculate the crowding effect of unreliability. When more insights in this mechanism come available, all effects of service unreliability may be properly incorporated in a CBA.

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