Australasian Transport Research Forum 2016 Proceedings
16 – 18 November 2016, Melbourne, Australia
Publication website: http://www.atrf.info

A New Method for Improving Temporal Integration in Transit Systems: A Case Study of Adelaide O-Bahn

Vahid Poorjafari[1], Wen Long Yue[2] and Nicholas Holyoak[3]

[1]School of Natural and Built Environments, University of South Australia, Adelaide, Australia

[2]School of Natural and Built Environments, University of South Australia, Adelaide, Australia

[3]School of Computer Science, Engineering and Mathematics, Flinders University, Adelaide, Australia

Email for correspondence: cxqvy002@mymail.unisa.edu.au

Abstract

Temporal coordination of services is a crucial aspect of integration in transit systems as it directly affects the waiting times imposed on transferring passengers. A number of methods have been proposed so far for improving temporal coordination in public transport systems. However, those methods are based on the number of transferring passengers which is often difficult information to collect in practice. This paper presents a novel method for reducing passengers' transfer waiting time without the need for transfer counts data. First, a quantitative index is developed as a measure of effectiveness for quantifying the level of coordination in transit systems. Then, a transfer optimisation algorithm is proposed for minimising the waiting times incurred by the passengers transferring between public transport services. A genetic algorithm is also developed as the solution technique for this algorithm and several computer programs were created for implementing the algorithm. To test the applicability of this method, Adelaide O-Bahn busway was selected as a case study and its existing timetables were modified using the proposed method. The numerical results of this application revealed a considerable reduction in the passengers' transfer waiting times over peak and inter-peak periods. This method can be used by transit planners and schedulers for assessing the level of coordination in transit systems, as well as for improving temporal coordination between public transport modes and lines, particularly in the absence of transferring passenger counts.

1. Introduction

Public transport systems intend to provide service between numerous origin-destination pairs in order to be able to compete with private cars. In practice, however, it is implausible and uneconomical to connect all origins and destinations with direct lines (Kim & Schonfeld 2014). Consequently, passengers often need to take more than one service to complete their journeys. In other words, transferring between different transit services is often inevitable for public transport users, especially in large urban areas.

The passengers transferring between transit services usually incur a waiting time between the related services. This waiting time, which is called transfer waiting time, is a direct consequence of temporal coordination between transit services (Teodorović & Lučić 2005). When public transport services are poorly coordinated, long and unendurable waiting times are imposed on transferring passengers. This can lead some passengers to stop using public transport as a travel mode (Ceder, Avishai & Perera 2014). In contrast, a well-coordinated system provides smooth transfers between different services with minimal delay for public transport users (Wu et al. 2015). Such a transit system can be considered as a viable alternative to private cars even in highly dispersed cities (Mees 2000, 2010). Hence, improvement of temporal coordination in transit systems, which is widely recognised as *timetable synchronisation* or *transfer optimisation*, is a crucial step in transit systems planning and timetabling.

Transfer optimisation is the process of setting timetables for all lines in a transit network for the purpose of reducing the waiting time imposed on transferring passengers (Castelli, Pesenti & Ukovich 2004; Tuzun Aksu & Yılmaz 2014). In network-wide transfer optimisation, all possible transfers occurring between transit line pairs in a network are taken into account and it is intended to minimise total transfer waiting time through appropriately setting departure times and arrival times of transit vehicles. This process is a complicated task by nature mainly due to the need for setting timetables for all lines while considering the operational limitations of transit systems and passenger requirements. Often, it may seem desirable to shift departure times and arrival times for a pair of transit lines to reduce the transfer waiting time between them. However, it may be undesirable and impractical on a network wide basis, as such a shift influences the coordination between these lines and other lines. That is why transfer optimisation is widely known as the most difficult task for transit planners and schedulers (Ceder, A., Golany & Tal 2001).

Due to its importance, transfer optimisation has been extensively addressed in previous studies and a number of methods have been proposed for this complex problem so far. Nevertheless, one of the major drawbacks to adapting the proposed methods is their dependence on the number of transferring passengers. Typical transfer optimisation methods are mainly based on the concept of minimising total transfer waiting time in transit networks. In other words, minimisation of total transfer waiting time has been commonly considered as the objective of such methods. Since the total transfer waiting time is the summation of all waiting times incurred by all transferring passengers in a transit network, the number of passengers transferring between different transit services (i.e. transfer counts) is a determinant factor required for implementing the proposed methods. In practice, however, such information is very hard to collect. Even if transfer counts are collectable for existing transit lines, no data are available for new lines at the stage of system planning and scheduling. Accordingly, a transfer optimisation method which is independent of the number of transfers could be more practical for improving temporal integration of transit systems, especially in case no information is available about transferring passenger counts.

This paper aims to present a method for reducing the waiting time imposed on transferring passengers in public transport systems without the need for transfer counts data. First, the transfer optimisation methods proposed in the literature are briefly explained and discussed. Then, a synchronisation quality index is presented as a measure of effectiveness for quantifying the quality of temporal coordination in transit systems. Based on this, a computational algorithm is developed for reducing transfer waiting times incurred by public transport users. The application of this method to a real-world transit network is also presented in this paper for the sake of testing the applicability of the proposed method.

2. Quality-Based Synchronisation

Parallel to the growing interest in developing efficient and attractive public transport systems over the recent years, a wealth of research has been conducted on transfer optimisation and several methods have been developed for reducing passengers' transfer waiting time. Despite some similarities, these methods are fundamentally different based on their objectives. The majority of the transfer optimisation methods proposed in the previous studies are intended to minimise the network-wide summation of waiting times incurred by transferring passengers. In this group of methods, all feasible transfers occurring between transit lines at all transfer points (i.e. transfer stations or stops) are taken into consideration and transit services are scheduled so as to minimise the total transfer waiting time in the network (Guihaire & Hao 2008). This objective is basically dependent on the number of passengers transferring between transit services, as well as the waiting time incurred by every individual transferring passenger. In such methods, in fact, transfer counts data are essential parts of the required information.

In practice, transfer counts data are not always readily available, particularly on a network wide basis, and collecting these data requires considerable resources (Currie & Bromley 2005). Such information is very difficult to collect by site observation, as recognition of origin and destination lines for every passenger is almost an impractical task at crowded transfer points. Interviewing passengers at transfer points also requires lots of surveyors, especially in the case of dealing with huge transit networks. Even if such a resource intensive task is doable, it is unlikely to be repeated over time, as required for updating public transport schedules. Transfer counts data could be extracted from automated fare collection (AFC) systems. However, plenty of public transport systems are not completely equipped with such systems, like those operating in most of developing nations. Moreover, AFC data are sometimes hard to obtain because of confidentiality considerations, in particular when transit systems are run by private operators. Furthermore, lack of transfer counts data for new transit lines (at the stage of planning and timetabling) is another issue, even if such information exists for functional lines. Such problems could hinder the application of the transfer optimisation methods to many functional transit systems. In fact, unavailability of transfer counts data is one of the biggest issues concerned with transfer optimisation methods (Currie & Bromley 2005).

In order to cope with this issue, another type of transfer optimisation methods has arisen over the recent years. These methods are independent of transfer counts data and aim to quantify the quality of transfers based on their waiting times, regardless of the number of transferring passengers. In fact, the major difference between transfer optimisation and quality index approaches is the dependence on transfer counts data. In such methods, a global index is typically used as a measure of effectiveness (MOE) for quantifying the level of coordination between transit services for the entire of a transit network. Therefore, the main aim of quality-based methods is to maximise the value of their quality indices through optimally scheduling transit services. Since the quality based methods are independent of transfer counts, they have a broader area of application in practice. Nonetheless, this approach has not received sufficient attention in previous research and very few studies have addressed it so far.

Fleurent, Lessard and Seguin (2004) presented a timetable synchronisation method based on the length of waiting time for each transfer. They introduced the concept of ‘trip meet’, which is also used in HASTUS transit scheduling software, in order to describe a possible connection between two trips at a transfer point. In their method, three different values are assumed as minimum, ideal and maximum waiting times for each trip meet. These values are to be specified by schedulers for each transfer based on walking distance and passenger flow at each transfer point. A weight factor is also assigned by schedulers to each transfer in order to represent the relative importance of a transfer compared to other transfers in a network. Based upon these parameters, a quality index (QI) is calculated for measuring the quality of synchronisation for each trip meet. In addition, the synchronisation quality index (SQI), which is the summation of all QIs, is used to quantify the level of service coordination in a transit network. Currie and Bromley (2005) also developed another synchronisation quality index based on SQI. They proposed a quantitative index called synchronisation quality ratio (SQR) as the ratio of SQI to its maximum possible value.

The SQI and SQR indices proposed in the mentioned studies are influenced by the parameters that are set by schedulers. Furthermore, these indices are developed based on transfer time rather than transfer waiting time. Transfer time consists of walking time and transfer waiting time. While transfer waiting time depends on temporal coordination of services in transit systems, walking time is the consequence of physical integration in public transport networks. In fact, walking time depends on physical characteristics of public transport networks (e.g. distance between stops or platforms, ease of access, etc.) and is not affected by temporal integration. In order to cope with the issues associated with the mentioned indices, a new synchronisation quality index which is only dependent on the actual waiting times incurred by passengers is presented in the following section.

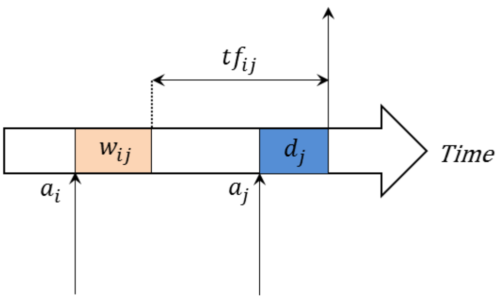
3. A New Synchronisation Index

In order to develop a quantitative index representing the temporal coordination status in transit systems, first it is essential to investigate the factors influencing transfer waiting time in transit systems. Let us imagine two transit lines *i* and *j* intersecting at a transfer point. The waiting time for the passengers transferring from a service in line *i* to the following service in line *j* consists of the time passengers spend on walking between two services (if required), as well as the waiting time for the next service of line *j* until its departure. Thus, the transfer waiting time (tf_{ij}) for the transferring passengers is defined as the interval between the arrival time of the passengers at line *j* platform or stop and the departure time of the related service from line *j* (Figure 1). This can be mathematically expressed as a function of the arrival times of transit vehicles operating in lines *i* and *j* at the transfer point (a_i,a_j), dwell time of the vehicles operating in line *j* at the transfer point (d_j) and the walking time (including boarding and alighting times) from *i* to *j* (w_{ij}), as follows:

$$tf_{ij} = a_j + d_j - a_i - w_{ij} \tag{1}$$

Considering Equation (1), the transferring passengers may encounter two extreme cases, namely, *no-wait* and *just-miss*.

Figure 1: Transfer waiting time between two transit lines



The no-wait scenario, which is the ideal situation for a transferring passenger, occurs when the passenger boards on the related service from line *j* just slightly prior to its departure time. Under this situation, no waiting time is imposed on the transferring passenger (tf_{ij} = 0) and the transfer time is only dependent on the walking time (including boarding and alighting times) between lines *i* and *j*. On the other hand, the just-miss scenario, which is the worst case for a transferring passenger, happens when the next service of line *j* departs the transfer point just before the passenger can board on. Using Equation (1), this situation can be expresses as:

$$w_{ij} = a_j + d_j - a_i + \varepsilon \tag{2}$$

Where, ε is a very little amount of time. This equation shows that the just-miss scenario occurs when the walking time is slightly longer than the interval between the departure time of the second service (line *j*) and arrival time of the first service (line *i*). In other words, the transferring passengers do not have sufficient time to alight from the first service, walk to the next service and board it on. Therefore, they need to wait for next service from line *j*. Ignoring ε, the transfer waiting time in this case equals the headway of line *j* ($tf_{ij} = h_j$).

On a network-wide scale, the highest level of synchronisation in a transit network is achieved when the no-wait scenario happens to all feasible transfers at all transfer points. In such a situation, the summation of transfer waiting times in the network (Z) becomes zero ($Z_{min} = 0$). In contrast, the lowest level of coordination in a transit system is the situation in which the just-miss scenario happens to all transfers in a network. In such a situation, the total transfer waiting time in the network reaches to its maximum value, which is equal to the summation of all the related service headways. In fact:

$$Z_{max} = \sum_{j=1}^{N} \sum_{c=1}^{M} \sum_{l=1}^{n_{ij}^{c}} h_j \tag{3}$$

Where, N is the number of directional lines in a network, M is the number of transfer points and n_{ij}^{c} is the number of feasible transfers from line *i* to line *j* at transfer point *c* over a scheduling period (e.g. peak period).

In practice, either of no-wait and just-miss scenarios is very unlikely to happen to all transfers in a public transport network. In other words, the level of temporal coordination in transit systems falls within these two extreme conditions. Therefore, the summation of waiting times for all transfers (Z) is between Z_{min} and Z_{max}. Based on this concept, a new synchronisation quality index can be proposed in this study as a global index for measuring the level of synchronisation in transit systems. This index, which is called Synchronisation Quality Score (SQS), is scaled from 0 (the worst level of coordination) to 100 (the best level of coordination) and is defined by the following equation:

$$\mathrm{SQS} = \left(1 - \frac{\mathrm{Z}}{\mathrm{Z_{max}}}\right) \times 100 \tag{4}$$

As mentioned before, this index is totally based on the actual waiting times incurred by transferring passengers and is not influenced by the other parameters like walking time.

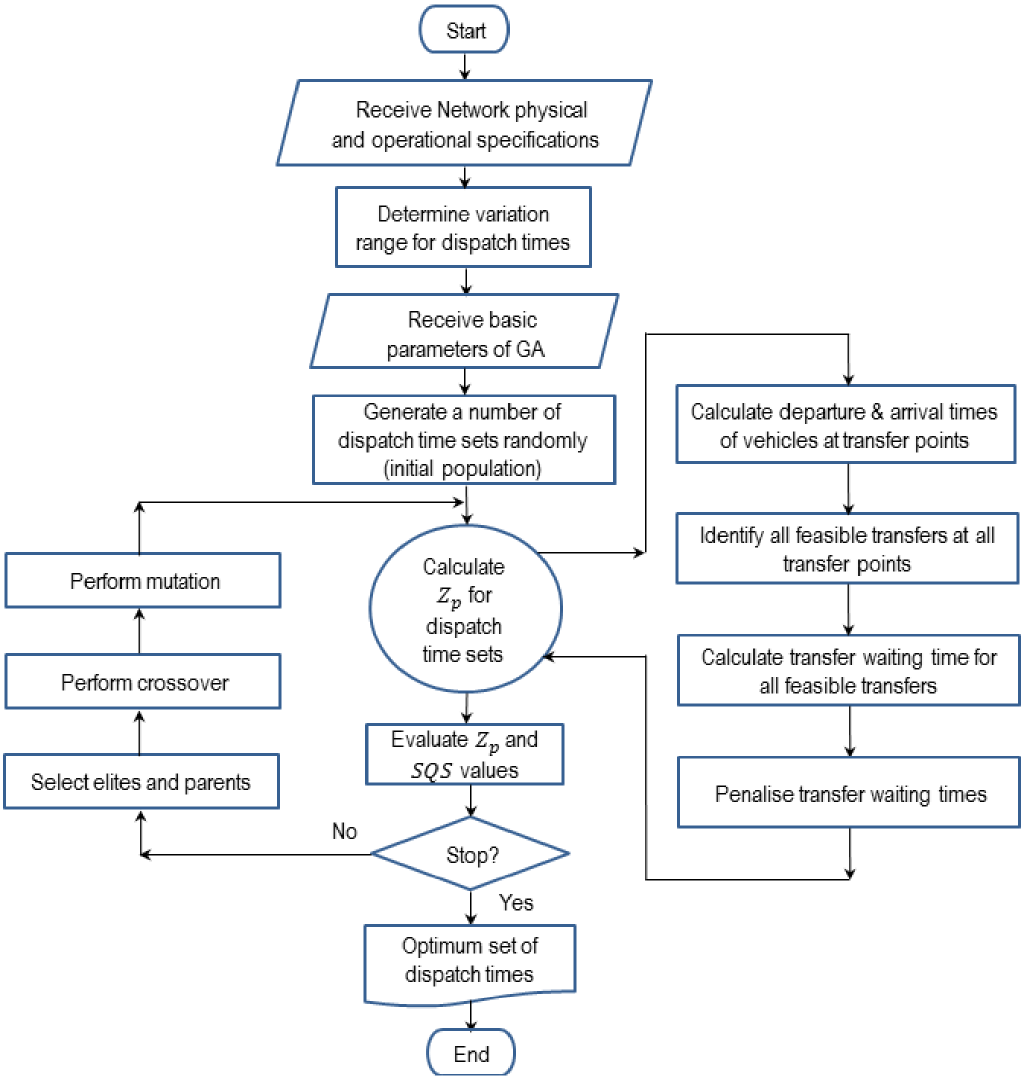
4. Optimisation Algorithm

The synchronisation measure presented in the previous section can be used not only for measuring the level of synchronisation in transit systems but also as an objective for transfer optimisation methods. In this study, SQS is integrated in an optimisation algorithm which attempts to maximise the level of synchronisation in public transport systems through modifying vehicles dispatch time. The proposed method is fundamentally based on the concept of providing relatively short and tolerable waiting times for all transfers in a network, regardless of transferring passengers quantity. This method provides an opportunity for automatically setting the dispatch times by which the highest level of synchronisation (i.e. highest value of SQS) is achieved. It should be noted that this approach is not intended to differ headways, as it affects the required fleet size. Rather, it aims to improve temporal coordination in public transport systems without altering the lines frequency determined according to passenger demand.

As described in the previous section, SQS is a function of network-wide summation of transfer waiting times (Z). Hence, different timetables resulting in the same values of Z lead to the same values of SQS. Let us imagine, for instance, transfer waiting times for three successive transfers from a line to another line are 10, 3, 1 and 5, 4, 5 minutes under two different timetabling scenarios. These two timetables result in the same value of SQS, as they have identical Z values ($Z = 14\ min$). When the transfer counts data are unavailable, however, the second timetable is more conservative as it provides relatively short transfer waiting times for all of these feasible transfers.

In order to overcome this issue, a penalty method is used in the proposed synchronisation method for the purpose of preventing long and unendurable waiting times for all feasible transfers. In this method, every transfer waiting time is exponentially penalised. Therefore, a huge penalty is applied to long transfer waiting times. Then, the summation of penalised transfer waiting times (Z_p) is used instead of the summation of actual transfer waiting times (Z) as the objective. Since this optimisation problem is a complex problem by nature, genetic algorithm (GA) which is a powerful optimisation technique is used as its solution algorithm. Figure 2 illustrates the general structure of the proposed optimisation algorithm.

Figure 2: General structure of the proposed synchronisation algorithm



This algorithm starts with receiving physical and operational specifications of a transit system including timetables and line frequencies. Based on headways, an acceptable range for variation of dispatch time is determined for every directional line. For a line with headway of h minutes, this range is considered as $[{-h}/{2}, {h}/{2}]$. Moreover, a parameter called importance factor is considered as a weight factor for transfers in order to reflect their relative importance compared to other transfers in the network. This parameter increases the flexibility of the method and enables schedulers to reflect their planning concerns and prioritise transfers with respect to their different times, locations and directions.

After receiving the basic parameters of the genetic algorithm (e.g. population size, proportion of elites, crossover and mutation probabilities), a number of dispatch time sets are generated randomly for all lines within the specified ranges. Then, Z_p is calculated for each of these dispatch time sets. In order to do this, departure time and arrival time of all vehicles at transfer points are calculated using the physical and operational characteristics of the network. Following this, all feasible transfers at each transfer point are identified. It should be noted that a transfer is considered feasible when its tf (computed by Equation 1) is equal to or greater than zero. Next, actual and penalised transfer waiting times are calculated for all feasible transfers and based on them, Z, Z_p and SQS parameters are computed for the entire network under the randomly generated dispatch time sets. If any of these sets is the optimum solution, the algorithm terminates and returns the optimum set of dispatch times. Otherwise, the dispatch time sets are modified using GA operators and new sets are produced. This cycle continues until the optimum set of dispatch times, which leads to the highest level of synchronisation in the network, is achieved.

In order to implement the iterative algorithm shown in Figure (2), several computer programs were developed using Matlab programming language. These programs aim to execute the optimisation algorithm and to assess the level of synchronisation based on SQS. It should be noted that these programs were then tested on a number of examples and their outputs were double-checked with manual calculations for the sake of debugging and ensuring the accuracy of their results.

5. Case Study

The transfer optimisation method presented in the previous section was applied to a real-world transit system in order to examine its capability in reducing transfer waiting time for public transport users. For this purpose, the O-Bahn guided busway which plays an important role in Adelaide’s transportation network was selected as the case study.

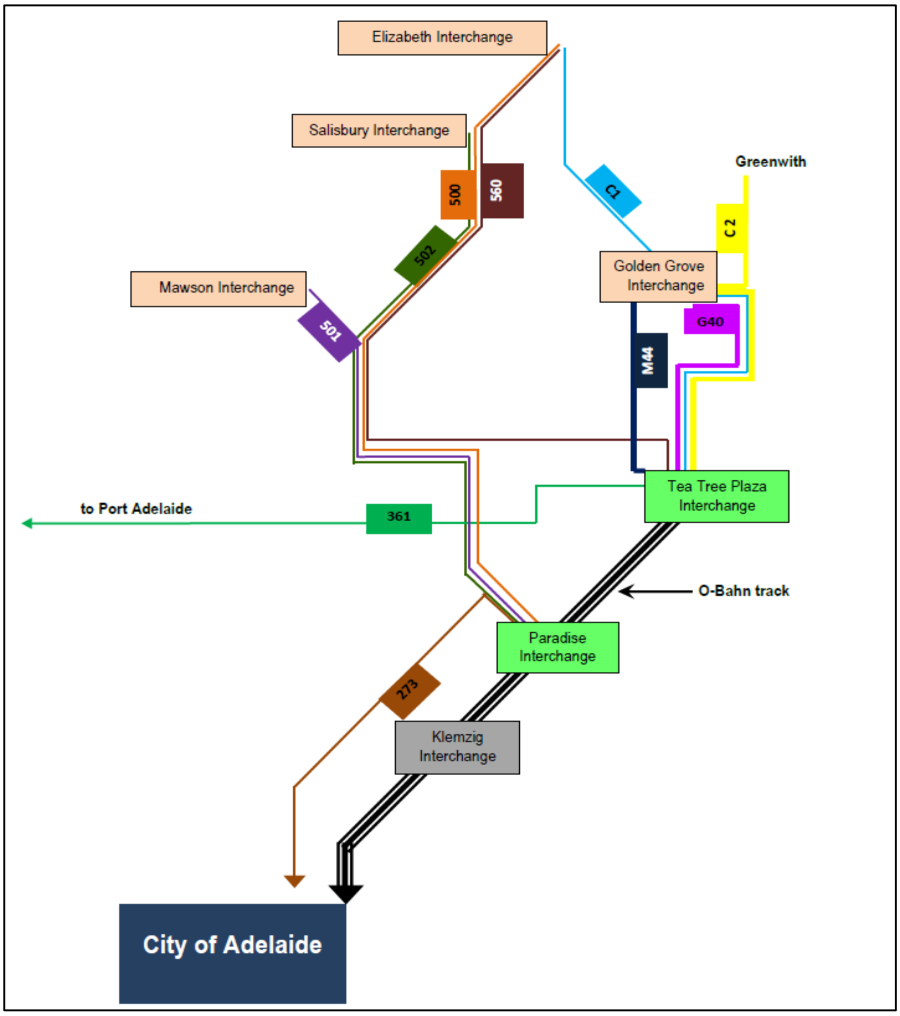
The bus system is a key feature of Adelaide’s public transport system. The bus network, which is configured as a radial network around the city, comprises a number interchanges, stops and routes providing connectivity between Adelaide’s city and suburbs. In this network, the O-Bahn is a crucial element in connecting the northern suburbs to the city, as well as to the southern suburbs of Adelaide. In fact, the O-Bahn is a vital north-south transit corridor in Adelaide carrying a great volume of passengers, especially over morning and afternoon peak periods.

The O-Bahn is a 12 km concrete-made common track for a number of bus routes (Figure 3). These routes are connected via the O-Bahn interchanges to a number of other bus routes serving the eastern and western suburbs of Adelaide. Hence, improving service connectivity in this network could lead to smooth transfers and prevents imposing long waiting times on transferring passengers. The O-Bahn includes three interchanges, namely, Klemzig, Paradise and Tea Tree Plaza. Klemzig, which is the first station located in a 3 km distance from CBD, is mainly operating as a bus stop for the suburb of Klemzig, rather than a transfer point. However, Paradise and Tea Tree Plaza interchanges have several platforms enabling passengers to transfer between different bus routes. In this study, ten O-Bahn bus routes which play a more important role in the bus network were selected as the case study for the proposed method. Figure (4) displays the O-Bahn bus routes selected for this purpose.

In order to apply the proposed method to the selected network, a range of data were collected from different sources. The headways of the selected bus routes as well as the dispatch times of the buses were derived from the existing timetables issued by Adelaide Metro, which is the responsible authority for Adelaide’s public transport system. The average running time of buses over the network segments were also obtained from the existing timetables and the network maps. In addition, dwell time of the buses at the selected interchanges as well as the walking distance between different platforms were collected through site observation and measurement. The site observation was performed over three successive working days including both peak and inter-peak periods. Afterwards, an extensive statistical analysis was conducted on the collected data in order to extract the average dwell time of the buses over peak and inter-peak periods, as well as the average walking time for each feasible transfer. It should be noted that different groups of passengers, including those who have mobility issues, were taken into consideration in the process of estimating the average walking time so that the feasible transfers are not missed even for the passengers with lower walking speeds. All of the mentioned data were then classified and used as the input data for the optimisation algorithm shown in Figure (2).

Figure 3: Adelaide's O-Bahn busway

Figure 4: Selected bus network



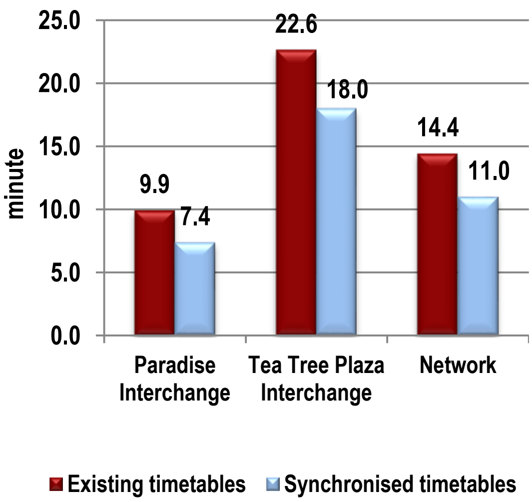
The operational characteristics of transit systems (e.g. vehicle running time, headway, etc.) are often different over various scheduling periods. In order to examine the impacts of the proposed method under different operational conditions, two different scheduling periods were considered: morning peak (7:00-8:00 am) and inter-peak (9:00-10:00 am). In this research, first the selected bus network was analysed under the existing timetables. Then, the proposed optimisation algorithm (Figure 2) was run to find the optimal set of dispatch times for the selected bus routes. In order to improve the efficiency of this algorithm, the best set of GA parameters were determined through sensitivity analysis, as follows:

- Population size: 100
- Crossover probability: 0.8
- Proportion of elites: 20%

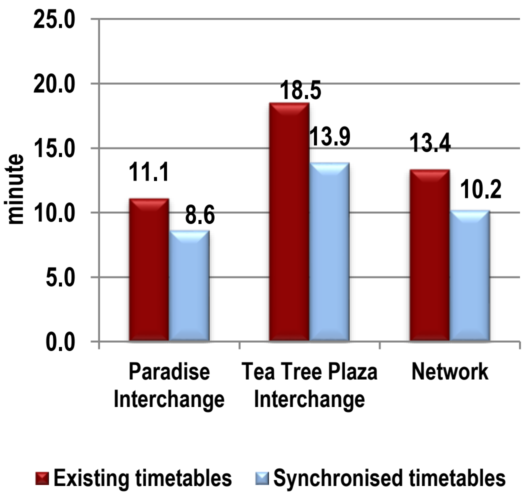
Under this setting, the optimum solution (i.e. the optimal set of dispatch times) was found by the proposed algorithm after a number of iterations. Based on the new dispatch times, the existing timetables were modified and the synchronised timetables were created. Afterwards, the network was analysed again under the synchronised timetables and the results were compared with the system performance under the existing timetables. This process was performed for both the peak and the inter-peak periods in order to investigate the impacts of the proposed methods on these scheduling periods.

Figure (5) displays the impacts of timetable synchronisation on the average transfer waiting time in the intended bus network. As shown in this figure, the average waiting time endured by the bus users for transferring over peak and inter-peak hours decreased considerably by the proposed synchronisation method. The average waiting time for each transfer in the network declined by 3.4 and 3.2 minutes over the morning peak and the inter-peak period, respectively. This equals a 24 per cent reduction in the waiting time incurred by transferring passengers over these scheduling periods. Figure (5) also reveals that both of the selected interchanges experienced a decrease in the average transfer waiting time although this reduction is not equal for these transfer points.

Figure 5: Average transfer waiting time in the selected bus network



peak hour



inter peak

In addition to reducing the average transfer waiting time, the proposed synchronisation method has led to increasing the number of transfers with relatively short waiting times in the selected network. Under the existing timetables, as shown in Figure (6), the waiting time for 25% of the transfers occurring over the morning peak is shorter than 5 minutes. After synchronising the timetables, this proportion rose to 38.8% of all feasible transfers. Similarly, the proportion of transfers with a waiting time of shorter than 5 minutes over the inter-peak hour increased from 25.1% to 42.3% (Figure 7). In contrast, the frequency of transfers with longer waiting times ($tf \geq 5\ min$) decreased under the synchronised timetables, compared to the existing timetables, for both of the peak and the inter-peak hours (Figures 6 and 7). This can be considered as a considerable improvement in the temporal coordination of bus services in the selected network. This outcome is also indicated by the change in the value of SQS.

Figure 6: Distribution of transfer waiting times over one hour of morning peak

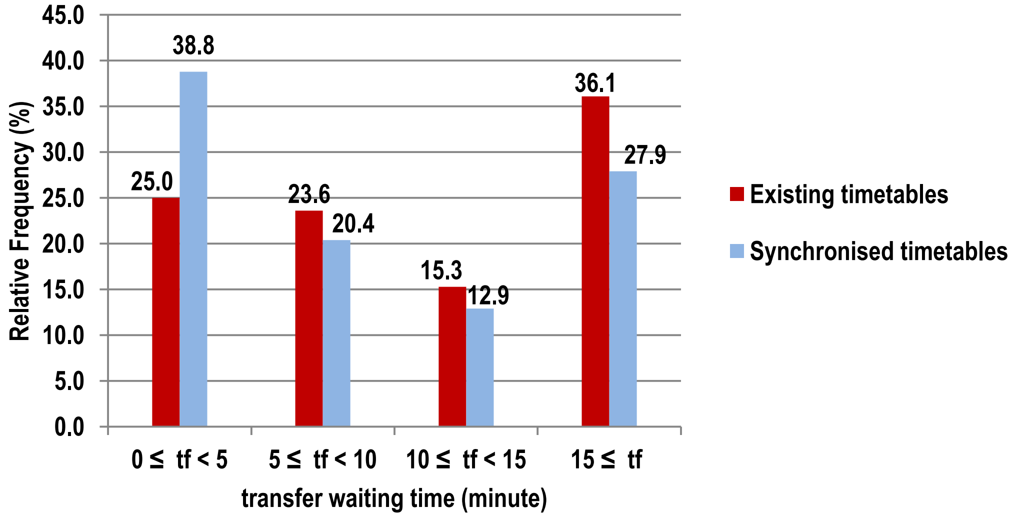
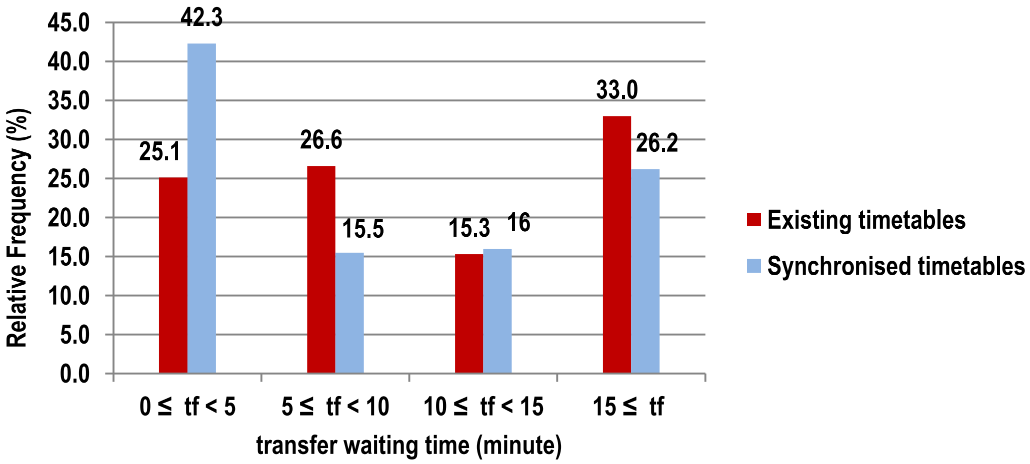


Figure 7: Distribution of transfer waiting times over one hour of inter peak



Under the existing timetables, as presented in Table (1), the synchronisation quality score (SQS) over the morning peak and the inter-peak periods is 47 and 52, respectively. As a result of synchronising the timetables, SQS increased to 61 and 64 for these periods, in order. This not only indicates an improvement in the level of synchronisation in the selected bus network, but also it reveals SQS could clearly represent the quality of temporal coordination in transit systems. Overall, this application showed applicability and effectiveness of the proposed synchronisation method under operational conditions of public transport systems.

Table 1: Synchronisation Quality Score (SQS) value for the case study

Scheduling period	Morning peak	Inter-peak
Existing timetables	47	52
Synchronised timetables	61	64

6. Conclusions

This paper has presented a novel timetable synchronisation method for improving temporal integration in public transport systems when the number of transferring passengers (i.e. transfer counts) is unavailable. First, a new index (SQS) was presented as a measure of effectiveness for assessing the quality of synchronisation in transit systems. Then, a transfer optimisation method, which is independent of transfer counts data, was proposed for improving temporal coordination in public transport systems. The application of this method to a real-world bus network revealed the applicability of the proposed method. Moreover, the numerical results of this application showed the capability of this method in reducing the waiting times imposed on the passengers transferring between different transit services.

In comparison with the previous synchronisation indices, SQS has some advantages. This index is only based on the actual transfer waiting times rather than other travel time components (e.g. walking time). In addition, it is independent of the parameters that need to be set by schedulers. Consequently, this measure is not influenced by personal judgment, which may differ from a scheduler to another. The synchronisation method presented in this work could also have a broader range of application, compared to previous transfer optimisation methods, since it is independent of transfer counts data. The idea of penalising long transfer waiting times is a novelty of this method. Further work could focus on combining the proposed method with physical integration of transit systems for the sake of providing smooth transfers for public transport users. Application of other optimisation techniques and comparing their results with genetic algorithm could also be another extension for this study.

References

Castelli, L, Pesenti, R & Ukovich, W 2004, 'Scheduling multimodal transportation systems', *European Journal of Operational Research,* vol. 155, no. 3, pp. 603-615.

Ceder, A, Golany, B & Tal, O 2001, 'Creating bus timetables with maximal synchronization', *Transportation Research Part A: Policy and Practice,* vol. 35, no. 10, pp. 913-928.

Ceder, A & Perera, S 2014, 'Detecting and improving public-transit connectivity with case studies of two world sport events', *Transport Policy,* vol. 33, 5//, pp. 96-109.

Currie, G & Bromley, L 2005, 'Developing Measures of Public Transport Schedule Coordination Quality', *28th Ausraliasian Transport Research Forum*.

Fleurent, C, Lessard, R & Seguin, L 2004, 'Transit timetable synchronization: evaluation and optimization', *Proceedings of the Ninth International Conference on Computer-Aided Scheduling of Public Transport (CASPT)*.

Guihaire, V & Hao, J-K 2008, 'Transit network design and scheduling: A global review', *Transportation Research Part A: Policy and Practice,* vol. 42, no. 10, pp. 1251-1273.

Kim, ME & Schonfeld, P 2014, 'Integration of conventional and flexible bus services with timed transfers', *Transportation Research Part B: Methodological,* vol. 68, pp. 76-97.

Mees, P 2000, *A Very Public Solution: Transport in the Dispersed City.*, Melbourne University Press., Melbourne.

Mees, P 2010, *Transport for Suburbia: Beyond the Automobile Age.*, London, Earthscan.

Teodorović, D & Lučić, P 2005, 'Schedule synchronization in public transit using the fuzzy ant system', *Transportation Planning and Technology,* vol. 28, no. 1, 2005/02/01, pp. 47-76.

Tuzun Aksu, D & Yılmaz, S 2014, 'Transit coordination with heterogeneous headways', *Transportation Planning and Technology,* vol. 37, no. 5, 2014/07/04, pp. 450-465.

Wu, J, Liu, M, Sun, H, Li, T, Gao, Z & Wang, DZW 2015, 'Equity-based timetable synchronization optimization in urban subway network', *Transportation Research Part C: Emerging Technologies,* vol. 51, no. 0, 2//, pp. 1-18.