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When less is more: exploring trade-offs in transit route concentration

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ABSTRACT

Route concentration involves withdrawal of selected bus routes to redeploy buses on major corridors to concentrate service frequency in those corridors at no net additional cost. Much research supports high frequency as a means to grow ridership and several practitioners have recommended route concentration. However research demonstrating the value of route concentration is limited. In particular gaps in knowledge about the longer walk access distances caused by route concentration need to be better understood relative to the benefits of higher frequency. This research paper explores the net impacts of route concentration on ridership using a theroetical network and some simple but robust representations of the impacts of route concentration on walk access, frequency and wait time including ridership impact. Results demonstrate that the route concentration options tested acted to increase ridership by up to 10% whilst operations costs were the same. They provide strong support for the concept of route concentration as a basis for route network redesign to improve service effectiveness. However the results also suggested that there is a finite limit to which route concentration might be deployed. In the options tested a 1.2km route density achieved the highest ridership growth compared to a base case of 300m route density. Though lower density options had lower ridership growth suggesting long walk access distances can act to limit ridership benefits if route densities become too low. Sensitivity tests suggests a 1.2km route density was consistently the best suggesting a robust result. Implications for practice and future research are discussed.

Abstract = 250 words (limit = 250 words)

Keywords: service frequency, walking time, waiting time, route concentration

INTRODUCTION

Ridership growth is one of the central aims of transit authorities worldwide [1]. Much evidence now suggests that high frequency transit is effective in growing ridership [2-4] however frequent services need large and expensive resources (vehicles, crew) which can make services financially marginal. Many scholars and practitioners have recommended redistributing transit network resources by withdrawing routes and services from selected locations and concentrating these services in major lines to create high frequency pools of service in key corridors forming major structural elements of the network [5-7]. We term this strategy 'route concentration'. While this strategy is likely to be at worst, cost neutral, it will act to increase walk access time for many passengers since concentrated corridors of frequency will be further away from areas where services are withdrawn. Research also indicates that long walk access as well as frequency are major concerns for passengers [8] so there appears to be no obvious solutions to this conundrum; should authorities concentrate routes or not?

This research paper seeks to explore the complex trade-offs involved in the transit route concentration problem using a simple transit network model which represents the major components of this problem; ridership impacts on service frequency improvement vs increased walk time and the transit route resource and cost impacts these imply.

The paper is structured as follows. The next section outlines the research literature on transit service concentration, as well as research on the valuation and measurement of components of the route concentration problem. This is followed by a description of the research methodology including the simple network model adopted for the study. Results are then described. The paper concludes with a discussion of key findings and their implications for practice including a discussion of research limitations and areas for future research.

RESEARCH CONTEXT

A review of the literature is now presented including research on the benefits of frequent service, research and practice evidence on the route concentration concept and then a review of research on the relative ridership responses to frequency and walk time.

The benefits of frequent transit

In a meta study of factors which would act to create large increases in bus ridership, Currie and Wallis [3] used evidence from a Delphi survey of leading international bus practitioners, a review of high ridership bus systems and even service elasticity evidence finding that service frequency was the single most effective lever for planners to use to increase ridership. However, the authors highlighted that this was not necessarily a cost effective lever since frequency can drive high costs. A follow on study by the same authors found that while increased frequency can drive ridership growth, it is also likely to increase subsidies in low density western urban environments [9]. A large number of studies now support this view including many adopting analytical approaches to identify factors influencing route level ridership; in each case short headways (or high frequency) were identified as the principle driver of high ridership [2, 10-13].

Route Concentration – Practice and Evidence

The work of transit theorist and planning practitioner Jarrett Walker has highlighted that the balance between concentrated frequency in major corridors vs a wider spatial spread of lower frequency routes is a major problem of western public transit network strategy [6]. His experience has suggested strong ridership and service effectiveness benefits from rebalancing resources to higher frequency corridors. European research also supports this view. The pan-European study of network design, HiTrans [5], recommended concentrating services on major corridors to achieve 'forget the timetable' frequencies which had added benefits of reducing the barriers created by transfers between routes which were easier to do on high frequency routes. A meta study of evidence from commercial operation of privatised bus services in the UK [7, 14] identified the most cost effective measures employed by commercial operators to increase profits. The single most cost effective measure was 'route simplification' including withdrawal of low frequency routes in low density areas and concentration of these routes into high frequency corridors with straight, direct routes. This principle is also behind the Bus Rapid Transit concept where frequency of service appears to be a major driver of quality design [11, 13, 15].

While the concept of route concentration looks appealing, research backing this strategy is not without its gaps. In a foundation study of ridership generation around bus routes looking at service frequency, wait times and walk access distances, Hopkins et al [16] found that walk access distances increased with higher frequency service. However the walk distance threshold for access to higher frequency routes is not unlimited. Few passengers will walk more than 10 minutes to access a bus service regardless of headway [16]. The implication is that there is some bound or threshold of route concentration which must act to limit access. In theory this should also act to limit ridership potential. Indeed researchers and practitioners have also voiced concerns about the equity implications of route concentration [6, 17]. If route concentration can benefit those living near major corridors, what happens to riders living outside of reasonable walk access distances to major routes. Problems of this type have been highlighted for older passengers with limited walk access distances. Clearly an analytical approach to better understand these trade-offs in service planning is needed.

Modelling Frequency, Wait and Walk Times in Network Planning

The academic and mathematical field concerning what is termed the 'transit network design problem' (TNDP) has concerned itself with the optimisation of routes and services including consideration of user wait and walk times and transit resource and profitability objectives [18-20]. To the authors' knowledge this field has to date not directly addressed the issue of route concentration as described above. In addition, the field is characterised by high quality complex mathematics. This has not lent itself well to widespread understanding and adoption of the methods developed in TNDP research by transit practitioners. It is the aim of this paper to adopt a more open, simple and easier to understand approach which might be better comprehended by transit professions so as to better influence practice.

Our understanding of the ridership impacts of frequency and wait time is well developed. A large range of meta studies of actual outcomes from revealed evidence suggest an elasticity of demand to service frequency of around 0.35 [7]. That means doubling the service frequency would lead to a growth in patronage of 35%. A common approach to measuring wait time is to take the rather simplistic approach that wait time is half the scheduled headway. The research literature distinguishes between the so called 'forget-the timetable' service and less frequent services where passengers tend to plan their arrival at stops/stations. There is general consensus that passengers randomly arrive at their stations, if service headway is lower than 10 -15 minutes. Thus average waiting time is equal to half the headway in these cases [21-23]. With longer headways passengers start to consult a timetable [24], so the waiting time function doesn't grow linearly but flattens out, as represented in Figure 1 and equation 1 [23, 25].

$$\boldsymbol{WT} = \boldsymbol{F} + \boldsymbol{G} * (\boldsymbol{HW})^{\boldsymbol{H}} \qquad (1)$$
$$F = 2;\ G = 0.75;\ H = 0.72$$

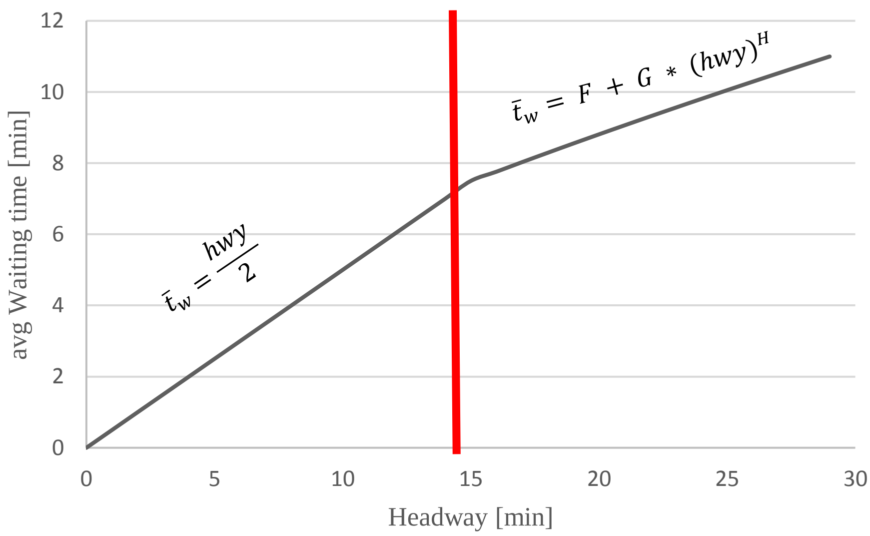


FIGURE 1 Average waiting time function.

It is worth pointing out that while the approaches noted above are effective in approximating wait time in most cases, research also illustrates that this is a complex field in practice. Bowman and Turnquist [24] proposed a more accurate choice model by dividing passengers into the groups of 'aware' and 'unaware' riders. Results show an overestimation of waiting times for the random arrival model and a higher passenger sensitivity to reliability than to service frequency. This theory finds further support, at least for the introduction of real-time information (RTI) on vehicle arrivals at bus stations. Paired with the increasing usage of mobile devices, unexperienced public transport riders now have better and more convenient access to timetable information. Journey planning applications took over the burdens of considering a printed timetable. Actual, as well as perceived waiting times, are lower among users obtaining arrival information from their mobile phones [26]. Evaluating the added-value of RTI they further found that the achieved reduction in waiting time by implementing RTI could alternatively be achieved by a 45% improvement of service frequency.

Ridership impacts of walk access are also well understood. In general a majority of riders in urbanised areas walk or use their bike to reach a public transport station/stop. With increasing distance, either local feeder services or the private car are the dominating modes to reach a transit station [27]. Average walking distances to bus or train stations are directly linked to the average stop spacing of a certain mode and their derived catchment areas. Different rules of thumb have established over the last sixty years. National guidelines and planning standards often suggest a maximum stop spacing from 400 m for local bus services to 800 m for higher quality services. The US Center for transit-oriented development uses 0.25 and 0.5 mile circles as a standard for defining catchment areas, hence the average walking distance to a transit station averages 400 – 800 m. This approach deduces from the assumption that people are willing to walk for about 5 – 10 minutes (based on a walk speed about 4.5 km/h) to reach a public transport station [28].It should be noted that willingness to walk is not only influenced by distance but among other factors also varies by personal characteristics, trip purpose, walking infrastructure and environmental conditions, weather and topography [29, 30].

This theoretical assumptions of average walking distances to public transport stops were verified by numerous analyses of transit networks. Daniels and Mulley [31] used data from the Sydney Household Travel Survey to analyse influencing factors on walking distance. The results show mean walking distances to train stations of 805 m, whereas walk trips to bus stops average 461 m. Hence this also reflects the supply level (number of stops; spacing) of those two modes. Further, the findings support evidence that people also walk longer distances than the often suggested 400 m to access public transport. Similar evidence for Brisbane was found by Burke and Brown [32], where the median walk to bus stops amounted to 490 m (mean = 600 m), while the median walking distance to train stations was 890 m (mean = 1.04 km). Also people in New York City tend to walk half a block further to reach BRT stations instead of local public transport stops [33]. Walker [6], who also refers to the several US studies in Kittelson & Associates, Brinckerhoff [1], points out that ridership decreases dramatically beyond the generally accepted walking distance of 400 m for local bus services, while faster services have higher catchment areas.

A major finding of research exploring passenger perceptions of wait and walk time is that passengers place a high value on this ‘out of vehicle’ time due to anxiety associated with waiting and physical efforts associated with walking. Wardman [34] gives an overview of international research exploring those values of out of vehicle time in relation to in-vehicle time. Summarising the findings between the late sixties and the turn of millennium, walk time is estimated to be valued at 1.6 to 2.4 times of equivalent in-vehicle travel time. Values for wait time are more widespread from 1.5 to 5.4 and averaging around 3 times in-vehicle time. However after conducting his own meta-analysis Wardman [34] concludes, that it is reasonable to use the “widespread conventions of transport planning”. He recommends a value for walk time and wait time as twice the value of in-vehicle time, but suggests a 2.5 weight for wait time as more appropriate. This approach is supported by a research project for the New Zealand Government, led by Booz Allen & Hamilton (NZ) Ltd [35].

METHODOLOGY

Low frequency services with meandering courses, as they are common practice in low density areas, don’t seem to be appealing to passengers, hence private cars are the dominating mode because of poor public transport supply.
In order to develop better public transport solutions for widespread and low density suburbs the objective of this research is to explore the trade-offs between frequency, wait time and walk access distance that occur when a low density transit network is adjusted to withdraw some routes and to use the resources on these routes to concentrate frequency on major corridors.
The research also seeks to use a simple approach to illustrate these trade-offs, hence a theoretical network is adopted (Figure 2) and some robust though simple methods are used to represent transit demand and supply effects of route concentration in low density areas.

The Base Network

Similar to ‘Squaresville’, introduced by Paul Mees [36], a grid-based model city comprised of 100 blocks is adopted. Transit routes operate north-south on roads 300m apart. Thus the area consists of 3,000*3,000 m, an area of 9 square kilometres.

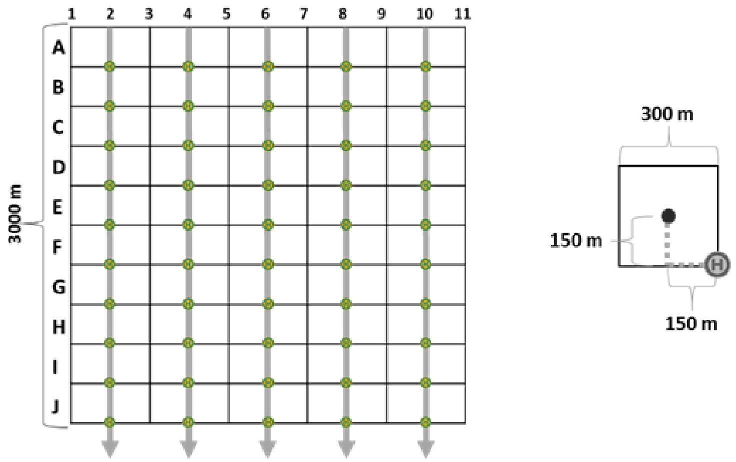


FIGURE 2 Route network (base case) and stop access.

Spacing between streets equals 300 meters and bus stops are placed on every corner of even numbered streets. Five bus routes run north-south from A to J and connect the observed area to trip destinations outside this model area. The trip origins of travellers who use these buses are all situated within the observed service zone, terminating in the area outside the zone. Thus no transfers are required. Further input parameters are defined as listed below:

- Vehicles available: 5 (one per route)
- Total route length: 7km
- Stop spacing: 300 m

- Operating speed: 21 km/h (based on typical industry values)
- Bus route round trip time (RTT): 20 min
- Layover Time: 5 min (based on typical industry values)
- Walk speed: 4.5 km/h (based on typical industry values)

Base Ridership

All passenger trips are generated out of the centroid of each block and are uniformly distributed over the network. A trip consists of access time to the bus stop (AT), waiting time (WT) at the bus stop, in-vehicle time (IVT) and egress time (ET) at its destination. To reach a bus stop a passenger first has to walk to the street network and then follows the street to the closest stop in the direction of travel. Hence the minimum walking distance to a bus stop adds up to 150 + 150 = 300 m, whereas the actual walking distance depends on route density which will be varied in the project case.

Representing Frequency Walk and Wait Time

Assuming an average walking speed of 4.5 km/h the minimal walking time amounts to 4 minutes. Wait times in the model are estimated using equation 1 (see earlier) so wait time is a function of headway (or frequency).

Representing Fleet/Resource Impacts

The operator has a maximum of 5 vehicles available to cater for the service area or one bus per route. This restriction directly influences the service headway (HW), which is determined by roundtrip time (RTT) and the number of available vehicles.

$$HW = RTT / \# Veh \quad (2)$$

Where roundtrip time RTT is calculated as:

$$RTT = trip\ time_{inbound} + trip\ time_{outbound} + layover\ time \quad (3)$$

By concentrating bus services on less routes, a higher service frequency can be achieved, but accessibility declines. How this affects ridership can be estimated by calculating how generalised cost for a passenger trip change. Changes in generalised costs can be used to estimate a forecast change in ridership by multiplying it by a generalised cost elasticity value.

Ridership Modelling

A simple generalised cost model is used to predict the ridership impacts of route concentration including wait time and walk access distance factors. The formula for the generalised cost model is as follows:

$$g = \frac{VoT}{(AT * w_1 + WT * w_2 + IVT * w_3) * 60} + f * w_4 \quad (4)$$

where:

g = generalised cost of the journey
VoT = Value of Time [$/h] — *IVT = in-vehicle time [min]*
AT = access time [min] — *f = fares [$]*
WT = wait time [min] — $w_{1\text{-}4}$ *= weights*

In this model trip fares are set to be AU$4 and the monetarised value of time is AU$20/hour. Changes in demand resulting from changes to generalised cost in the modelling are estimated using a generalised cost elasticity of -1.0 based on meta studies of industry evidence [37].

Table 1 shows the average generalised cost value for the base case network.

TABLE 1 Average Travel Time and Weighted Travel Time (Base Case)

Base Case	Trip Time	Weight	Weighted Trip Time
Access Time [min]	4.00	2	8.0
Wait Time [min]	14.51	2	29.02
In-vehicle Time [min]	16.14	1	16.14
∑ travel time [min]	34.65		53.16

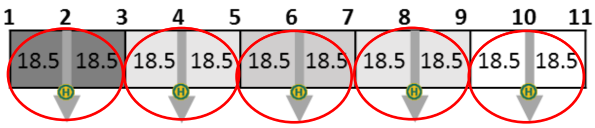
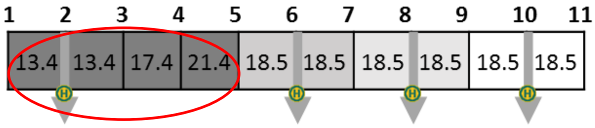
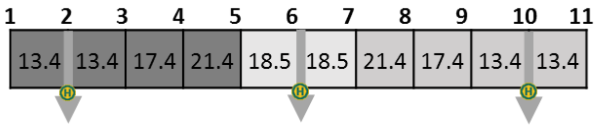
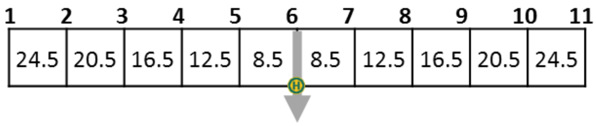
Each bus line attracts riders directly from neighbouring blocks, equivalent to 20% of the ridership in the observed service zone (see Table 2). Walking distance to a bus stop is similar across the entire service area, namely 300 m = 4 minutes. Given a total route length of 7 km the roundtrip time equals 45 minutes. Applying the formula for average waiting time, presented in equation 1, this results in an average waiting time of 14.51 minutes. IVT depends on the length of the journey and equals 20 minutes for the whole trip from stop A to the terminal stop and about 12.3 minutes when boarding at stop J.

Average values for the whole service area are calculated to compare different scenarios. Table 1 shows the average time needed for the defined trip segments in the base case. As discussed earlier, access time and waiting time are valued higher than actual in-vehicle time, because of higher inconvenience to passengers. The suggested weights of twice the IVT [34, 35] are applied here. The average trip time for the base scenario is 34.65 minutes. Accounting the disutility for out of vehicle time (AT + WT), the perceived trip time increases to 53.16 minutes.

Option Design for More Concentrated Routes

To illustrate the trade-offs between frequency and walk accessibility in route concentration, four project cases are designed. In each case one more bus route will be removed from the theoretical service area, in return frequency increases in the remaining routes since buses saved are used on the other routes. Table 2 illustrates the base and option scenarios and how the key variables in the analysis vary as a result.

TABLE 2 Base Case and Option Structure – Generalised Cost Components

<table>
<tr><td>Base Case</td><td>
</td><td>5 Routes
Same frequency and accessibility on every Route →
- Headway = 45 min
- Access time = 4.5 min</td></tr>
<tr><td>PC 1:</td><td>
</td><td>4 Routes
Doubled frequency on Route 2 →
- Headway Route 2 = 22.5 min
- Headway Route 6, 8, 10 = 45 min</td></tr>
<tr><td>PC 2:</td><td>
</td><td>3 Routes
Additional doubled frequency on Route 10 →
- Headway Route 2, 10 = 22.5 min
- Headway Route 6 = 45 min</td></tr>
<tr><td>PC 3:</td><td>
</td><td>2 Routes
New Route distribution to 4 and 8
Headway: 18 min</td></tr>
<tr><td>PC 4:</td><td>
</td><td>1 Route
All available resources on Route 6
Headway: 9 min</td></tr>
</table>

In project case 1, route 4 was removed from the network. Consequently, passengers between streets 3-5 have a longer access distance to the next bus stop, which now would be either on street 2 or 6. As compensation for the decreased service coverage, the available vehicle formerly from route 4 can be used to double the frequency on route 2. The former waiting time of 14.51 minutes drops to 9.44 minutes for passengers in blocks 1-4 and remains steady for passengers in blocks 5-10. Thus, average waiting time in this scenario could be reduced by about 2 minutes to 12.5 minutes, while the average access time increases by only 1.6 minutes to 5.6 minutes. As IVT remains the same, no further attention is given to this at this stage. The same procedure applies for project case 2. After eliminating route 8 from the network, passengers from block 7 will step over to route 10. The remaining routes 2 and 10 can attract more passengers because of short headways, while passengers directly neighbouring route 6 minimise their travel time by choosing route 6 because of the short access time.

In project case 3, one more route is eliminated from the network and the active routes are redistributed to streets 4 and 8. As a result of this measure, demand splits equally on both routes, which are now served with an 18 minute headway. Out of vehicle time can be reduced for 80% of the passengers, however 20% are placed worse than in project case 2. Finally, project case 4 concentrates all available resources on one central line, resulting in a 9 minute headway. This results in an average waiting time of 4.5 minutes for all passengers, but also incorporates highly increased access distances.

Sensitivity Tests

Because the analysis is simple and theoretical, some sensitivity tests were undertaken to explore how results might vary if alternative model parameters were selected. In particular, alternative values for the weighting of walk and wait time were explored, including:

Base Case

- Access Time (AT) weighting=2 Wait Time (WT) weighting =2

Sensitivity Tests

- Access Time (AT) weighting=1 Wait Time (WT) weighting =1 (Unweighted Test)
- Access Time (AT) weighting=2 Wait Time (WT) weighting =2.5 (High Wait Time Weight Test)
- Access Time (AT) weighting=2.5 Wait Time (WT) weighting =2.0 (High Walk Time Weight Test)

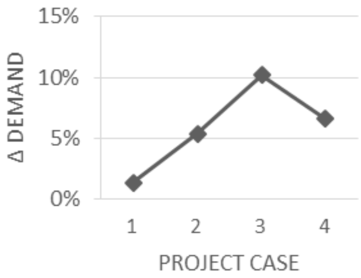
The outcomes of route and network modelling using the methods described above are outlined in the next section.

RESULTS

Table 3 shows the ridership impact results for each project case described above.

TABLE 3 Impacts of Service Concentration on Travel Demand

	Weight	BC	PC 1	PC 2	PC 3	PC 4
Average Weighted AT [min]	2	8.0	11.2	12.8	14.4	24.0
Average Weighted WT [min]	2	29.0	25.0	20.9	16.6	9.0
Average Weighted IVT [min]	1	16.1	16.1	16.1	16.1	16.1
Average trip time [min]		*53.2*	*52.3*	*49.8*	*47.1*	*49.1*
Average Generalised Cost of Travel [AUD]		*21.72*	*21.43*	*20.62*	*19.71*	*20.38*
Change in Average Generalised Cost			*-1%*	*-5%*	*-10%*	*-7%*
Forecast Change in Demand			*1.33%*	*5.36%*	*10.21%*	*6.57%*



This indicates that:

- In general, all route concentration options act to increase demand
- However, the degree of route concentration is important. Project cases 1, 2, 3 and 4 are all progressions of the level of route concentration. However, project case 3 has the highest increase in demand of 10%. Project case 4 is a further progression of route concentration beyond this yet this has a LOWER demand increase than project case 3.
- The implication is that while route concentration is successful in growing ridership at no net additional financial cost, too much concentration acts to increase walk access distance to a level that ridership growth is limited.

These findings present a clear case for route concentration. They also suggest that some degree of balance is required in the degree of concentration to manage additional walk access distances. In this case, a route density of 1,200m achieved the highest ridership growth compared to a base case 300m bus network. Further route concentration to a density of 1,500m acted to reduce net ridership compared to the 1,200m option.

Figure 3 illustrates the results of the ridership growth forecasts for the sensitivity tests.

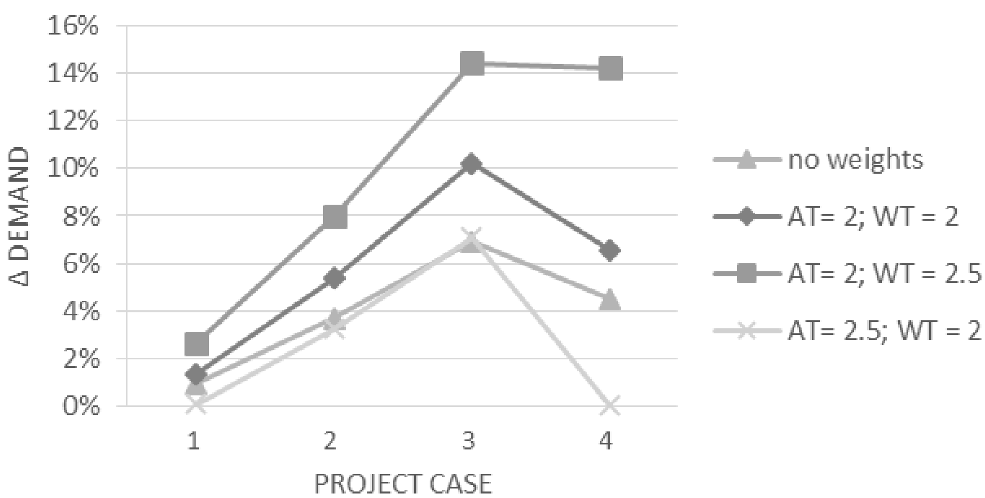


FIGURE 3 Ridership forecasts for sensitivity tests.

This indicates that:

- In all cases, project case 3 (route consolidation to a 1.2km route density) acted to increase ridership more than the other options tested regardless of the scale of changes in parameter weightings applied.
- Removing weighted out of vehicle time parameters acted to reduce the scale of ridership increases.
- Higher weights applied to wait time act to increase the level of ridership growth modelled more than for all other sensitivity tests undertaken.

Overall, the sensitivity tests suggest a consistent rating for project case 3 as the best of those tests is a robust result.

DISCUSSION AND CONCLUSIONS

Route concentration is the withdrawal of selected routes to be redeployed on major corridors to act to concentrate service frequency in those corridors at no net additional cost. Much research supports the concept of high frequency as a means to grow ridership and several practice reviews have recommended route concentration as a general practice for redevelopment of transit networks. However, research demonstrating the value of route concentration is limited. In particular gaps in knowledge about the longer walk access distances caused by route concentration need to be better understood relative to the benefits of higher frequency. This research paper explores the net impacts of route concentration on ridership using a theroetical network and some simple but robust representations of the impacts of route concentration on walk access, frequency and wait time including ridership impact. Results demonstrated that the route concentration options tested acted to increase ridership by up to 10% whilst operations costs were the same. They provide strong support for the concept of route concentration as a basis for route network redesign to improve service effectiveness. However, the results also suggested that there is a finite limit to which route concentration migh be deployed. In the options tested, a 1.2km route density achieved the highest ridership growth compared to a base case of 300m route density. On the other hand lower density options had lower ridership growth suggesting long walk access distances can act to limit ridership benefits if route densities become too low. Sensitivity tests of the perceptual weightings for walk access and wait time suggests a 1.2km route density was consistently the best of the options tested regardless of the sensitivity tests employed. This finding also suggests a robust result.

The major implication of these findings for planning practice are that substantive benefits at little or no cost lie in redesigning bus networks to concentrate frequency on major corridors by redeploying vehicles and crew from selected routes to those major corridors. But, planners need to make sure they do not go too far in route consolidation; in this research route densities of 1.2km were optimal; lower density networks than this will reduce net service benefits. Planners would also be wise to consider the equity impacts of route consolidation. While route concentration is advisable for ridership, revenue, cost and service effectiveness rationales, there is a danger that the longer walk access distances imposed on users might act to disenfranchise an important sector of the market and this may be unacceptable politically. Further planners and transit agencies should consider route concentration as an instrument to politically justify the implementation of priority treatments on the remaining routes. This can improve service reliability and hence ridership satisfaction.

The methodology adopted in this study is not without its limitations. The bus resource and frequency levels tested are as low as is possible. Would similar findings result for higher frequency and better resourced systems? This is clearly an area for future research. Also 45 minute headways seem to be unusual in practice for urban settings. Although they can be justified for low frequency services, further research should adjust the model towards more real world orientated headways. In addition, the walk access topology and ridership patterns tested are remarkably simplistic. There is much scope to employ these methods on real world cases to explore the option of route concentration.

Nevertheless the approach presented is easy to adopt and while simplistic can robustly represent the major components in the route concentration problem. The results present a strong justification to implementing route concentration as a strategy to improve service effectiveness on transit systems internationally.

LIST OF FIGURES

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