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Original Article

Improving the accessibility to Leeds Bradford International Airport

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Abstract

Accessibility to an airport is essential for air travellers since late arrival will result in missing a flight and financial loss. During the peak period, arrival at Leeds Bradford International Airport (LBIA) tends to be more vulnerable due to delays and queues at particular junctions in the road network. To improve the accessibility during this period, several improvements in the road network have been carried out and simulated using SATURN (Simulation and Assignment of Traffic in Urban Road Networks). The results show that the improvements in the network managed to reduce the generalised cost of travel because it has brought benefits for air travellers. This study found that junction improvement has brought monetary benefits equal to 153.67 pounds from 261 trips to LBIA which occurred during the morning peak period (08.00-09.00 AM).

Keywords: accessibility, airport, user benefits

1. Introduction

1.1 Background

Every air traveller desires to be punctual when arriving at the airport. Missing a flight will result in financial loss. To meet the flight punctually the travel time to the airport must be reliable. Thus, reliable travel time becomes essential. In addition, travel time to the airport is also a cost. Koster *et al*. (2011) claimed that the cost of travel time to access an airport ranges from 0% to 30% of total travel cost for business or non-business travel.

Air travel is dependent on the road network to access the airport in Leeds and the surrounding areas. There are two main access roads from Leeds to LBIA. From Leeds, car travellers might use link A660 or A65. Those two links head to the Outer Ring Road (A6120). After reaching the Outer Ring Road, travellers can directly use the shortest paths through Scotland Ln or Cookridge Ln. Travelers can continue driving through link A660 and A65 or other possible routes and enter link A658 which heads to the airport (Figure 1).

Accessing the airport using the road network is likely to cause extended travel time since high traffic flows tend to cause delays. The Leeds Bradford International Airport Connectivity Study (2014) found high traffic flows in several link accesses to the airport (A658, A6120, A65, A 660). In the peak hour period, congestion and queuing also occurred around several junctions and roundabouts (junctions; A658/A660, A657/A658, roundabout; A65/A658, A65/A61 20, A657/A6120). On the other hand, travel demand to the airport is predicted to gradually grow in the following years. The Wharfedale and Airedale Review Development Group (2011) reported that the number of airport passengers increased from 1.4 million in 2004 to 4.3 million in 2011, and

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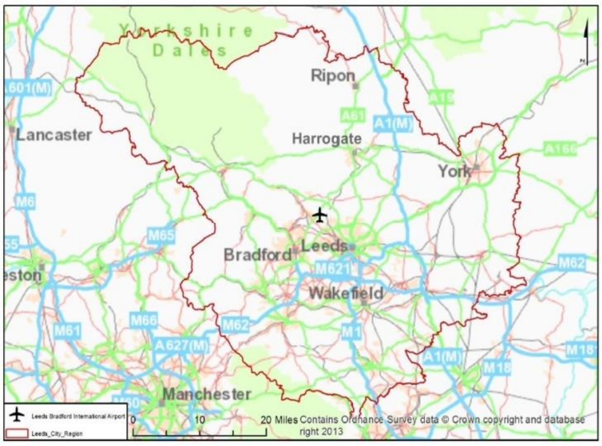


Figure 1. Location of LBIA.

the airport management company has further plans to increase passenger numbers to 5.1 million in 2016 and 7 million by 2030. Without any interference (do-nothing) this amount of traffic will potentially burden the road network capacity as well as the level of accessibility.

1.2 Research aim

This research aimed to generate alternative measures to increase airport accessibility during the peak road traffic period. Moreover the main objective of the research was to find the benefits from road network improvement and where the maximum moving occurs. In this case the critical time of traffic is at the morning peak hours. A concern of the study is also to analyze the improvement of the road network from the supply side not from the demand side such as improvement of public transport. As accessibility increases it is expected that air travellers will experience shorter journey time and lower travel cost, thereby deriving a monetary benefit.

2. Materials and Methods

2.1 Defining accessibility

Accessibility can be defined simply as the ability to reach or enter a destination (Oxford Dictionaries, 2015). In a more comprehensive way "*accessibility refers to the ease of reaching goods, services, activities and destinations, which together are called opportunities*" (Litman, 2015). Further, Litman also describes various meanings of accessibility from certain perspectives and some of these definitions are:

- In a general context, accessibility can be referred to physical access to goods, services and destinations, of which people need transportation as a physical access means.

- In road engineering, accessibility refers to the ability of a road network to connect the adjacent places. Road access is considered to be limited or poor due to an insufficient number of roads to connect the adjacent places. Limited access is not always considered a negative perception as this is part of road access management particularly in access to highways that can be managed by limiting intersections, off-ramps, and on-ramps.

- In the geography and urban economics perspective, accessibility refers to the ease of a particular location or area that can be reached.

Accessibility represents the generalised costs such as, time, money, discomfort, and risk that are needed to reach the desired activities. Generalised cost is a combination of monetary costs and time. Hence when the marginal financial costs of travel are relatively low, i.e. the cost spent by a car owner to travel, the travel time might become a dominant component of accessibility (Victoria Transport Policy Institute, 2015). According to this argument, it can be concluded that a lower generalised cost of travel will increase the level of accessibility of certain places.

2.2 Airport accessibility

Based on the general definition of accessibility described in the previous section, the understanding of airport accessibility can be considered as the capacity of an airport to be reached from other locations with the lowest generalised cost of travel which indicates higher accessibility of the airport. Kouwenhoven (2008) divided the definition of airport accessibilities into three categories:

a. Only taking into account the travel time as the measure of accessibility:
   - The travel time needed to reach an airport
   - All locations in the area from where the air travellers can reach the airport in a certain time

b. Considering other characteristics, for example travel costs, parking costs, reliability of travel times, and service levels, the reliability of travel times and service levels are then converted into a monetary cost using the value of travel time, value of reliability, and the value of service. The total monetary cost of all travel components is then called generalised cost of travel.

c. As the two previous measures are only applied for single modes (car), the third measurement is to consider multiple modes, e.g., car, bus, and train, into account to measure accessibility.

2.3 Alleviating road congestion measures

A comprehensive program is needed to alleviate road congestion. The program involves the components of a transportation system such as the traffic demand, supply infrastructure, system activities, transport authorities, and decision makers. This program includes short term and long term alternative measures. This program should work together to complement and support one another. The Institute of

Transportation Engineers (1989) describes several measures that can be taken. These measures include traffic signal timing improvements, intersection improvements, turn prohibitions, street widening, and building new access roads.

2.4 Application of consumer surplus theory for transport users

The consumer surplus theory has been applied to calculate user benefits in the transportation sector. This theory suggests that the consumers will experience additional benefits due to the perceived excess cost.

Generally, transport demand is influenced by transportation costs where a decrease in cost will impact an increase in demand. This relationship can be represented in the traditional downward-sloping demand curve where the demand curve represents the benefits of the travellers with an additional trip at different levels of demand.

In the case of a new transport scheme (do-something scenario) that aims to reduce the transport cost from the current situation P^0 to P^1, it will impact the increasing trip demand from T^0 to T^1. This improvement will result in an increased surplus for the travellers that can be represented as $T^0 \times (P^0 - P^1)$. Then the consumer surplus for additional trips is $0.5 \times (T^1 - T^0) \times (P^0 - P^1)$. This two consumer surplus can be combined to produce a formula called the 'rule of a half' and results in a graph (Figure 2).

$$\text{Consumer surplus} = 0.5 \times (T^0 + T^1) \times (P^0 - P^1)$$

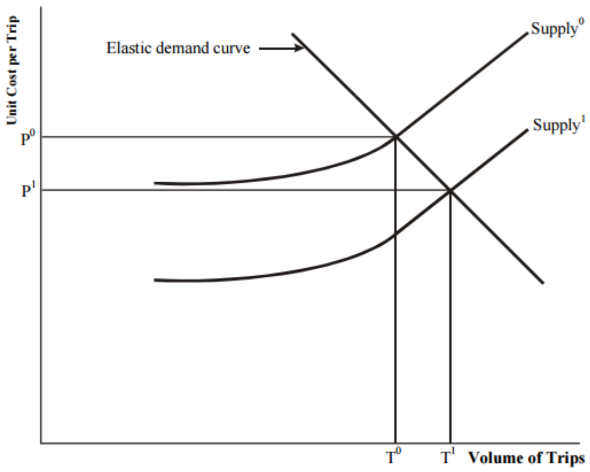


Figure 2. Relationship between travel cost and transport demand

2.5 SATURN modelling overview

Road network assignment involves the demand and supply as the input. The road demand is represented by the trip matrix where a certain zone origin-destination (O-D) pairs with its number of trips are stored. Zone O-D pairs can be seen in Table 1. On the other hand, the supply of the demand is the road network as the paths where the traffic will flow from origin zones to destination zones. The output of the assignments is the route chosen by each road user. From the output it can also be observed how many users choose specific routes. Hence the flow of each link in the network can be identified to observe which routes have good performance and which routes have poor performance (for example; over capacity). Furthermore, by assigning the road network it can predict the journey time and travel cost from each zone O-D pair. This assignment outputs will be an important tool to evaluate the performance of the road network. The structure of an assignment model can be seen in Figure 3.

Table 1. Zone O-D Pairs.

No	O	D	Trips	Zone
1	1233	724	13.89	Baildon
2	727	724	7.081	Otley
3	1704	724	6.368	Manchester
4	1401	724	6.295	Harrogate
5	734	724	5.319	Otley
6	746	724	4.528	Yeadon
7	237	724	4.012	Farsley
8	1600	724	3.957	York
9	343	724	3.606	Horsforth
10	719	724	3.587	Otley
11	726	724	3.525	Yeadon
12	605	724	3.42	Farnley
13	226	724	2.911	Greenhill Rd
14	733	724	2.63	Bayton Ln
15	219	724	2.626	Bramley
16	1230	724	2.524	Ravenscliffe
17	227	724	2.376	Greenside
18	229	724	2.142	Greenside
19	1229	724	2.128	Idle
20	1240	724	2.124	Ilkley
21	1263	724	1.993	Shipley
22	367	724	1.956	Kirkstall
23	1228	724	1.832	Bradford
24	1217	724	1.783	Bradford
25	1262	724	1.737	Burley in Wharfedale
26	1215	724	1.722	Bradford
27	438	724	1.495	Roundhay
28	725	724	1.474	Rawdon
29	715	724	1.471	Tinshill
30	351	724	1.469	Horsforth Woodside
	Total		**101.98**	

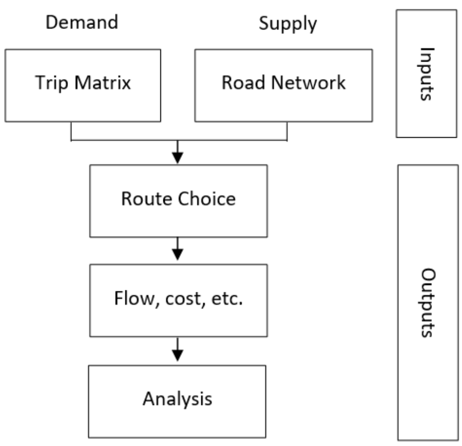


Figure 3. General structure of an assignment model.

The road assignment in SATURN (Simulation and Assignment of Traffic in Urban Road Networks) was carried out following the general model of road assignment as it was discussed in the prior section. The assignment process involves two input files: the network and trips matrix. The ASCII network file is built and stored in .DAT. Similarly the matrix file might also be developed from the ASCII file and saved as .DAT. To run the simulation these ASCII files, both network and matrix, should be converted to binary files. A feature in SATNET is used to convert a network .DAT file to the .UFN binary file. While the matrix ASCII file to be converted uses the feature MX to produce .UFM, these two binary files then are ready to be used as the input of the assignment process. The road assignment and simulation in SATURN can be conducted under the module SATALL. The output of the assignment and simulation is the so called binary file .UFS. This file contains the information of the assignment and simulation such as the amount of flow in each link, number of trips for each zone O-D pair, the simulated traffic in junction, as well as traffic delay and queue. All the information and results in .UFS can be analysed further in P1X in which the researcher will be able to measure the volume-capacity (V-C) ratio in links and junctions, average delay and queue, and also the average speed. The structure to run the basic SATURN model can be seen in Figure 4.

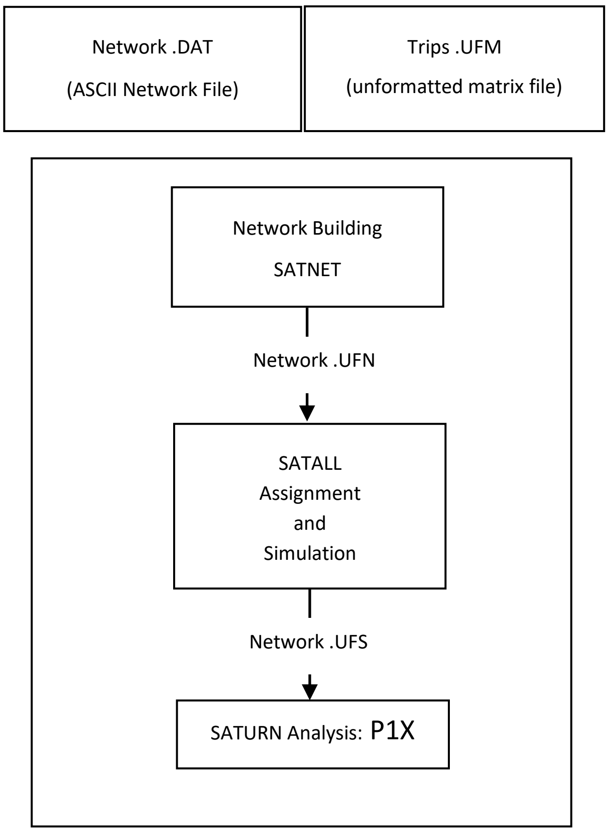


Figure 4. Running the basic SATURN model using SATALL.

2.6 Trip matrix factoring

In SATURN the module factoring a matrix is used to adjust the trip demand whether increasing or decreasing its cell values by setting a growth factor (weight) to the observed matrix.

$$T_{ij} = f \,.\, T_{ij}$$

where *f* is a weighting factor defined by the researcher and Tij are the cells factored that could be the whole cells of a matrix or selected cells within a matrix. The weighting factor (*f*) is defined by 1.1 as it is assumed that the traffic growth in Leeds and its surrounding regions will be around 1.5% to 1.73% per year (Mitchell, 2002; DfT, 2014). The trip data in this research was collected in 2009, therefore the traffic growth in the six-year period (from 2009 to 2015) is assumed to be 10%.

2.7 Improving the road network using P-MAKE network editor

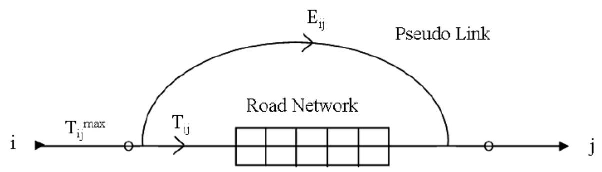
Network editing in SATURN is basically divided into two ways:

- Editing the existing network ‘properties’ such as link capacities, and;
- Editing the network’s ‘topology’, for example creating or eliminating nodes, links or turns.

The road network might be improved using several features available such as ‘edit simulation nodes’, ‘add links’, and ‘change the link properties’.

2.8 SATURN Elastic Demand Assignment

It is widely believed that reducing travel time and cost will induce more trips in the network. These additional trips are defined in SATURN as an excess trip. In the elastic demand assignment, SATURN creates for each origin (i) and destination (j) pair an imaginary link known as pseudo link to accommodate this excess demand. The new total trips, because of the decrease in cost, are then distributed through the real network or pseudo link. The trip choosing the real route is then represented as T_{ij}, whereas the trip choosing pseudo link is represented as E_{ij}. In this study the excess trips were potentially generated due to decreased travel time and cost as the road network became improved (Vliet, 2014). The trips distribution in elastic assignment are illustrated in Figure 5.



Source: Vliet, 2014

Figure 5. Pseudo link illustration in elastic assignment.

Demand is considered to be elastic if the number of trips from i to j represents the demand function of the cost.

The cost variable itself can be represented by the travel time consumed between i and j. In other words a longer travel time will be considered as a higher cost.

$$T_{ij} = f\,(c_{ij})$$

Following the demand function rules, it is well known that a reduced cost will bring about an increase in demand. In this assignment, the less travel time consumed between two O-D pair of zones i and j is assumed to generate more trips between those zones.

There are several ways to estimate the number of induced trip (additional demand). One of the alternative methods is the power law relationship where the ratio of cost is altered by the power of an elasticity parameter ‘p’:

$$T_{ij} = T_{ij}^{0}(c_{ij}/c_{ij}^{0})^{p}$$

where

T_{ij} : total trips by do-something scenario
T^{0}_{ij} : total trips by do-nothing scenario
c_{ij} : travel cost from zone i to j by do-something scenario
c^{0}_{ij} : travel cost from zone i to j by do-nothing scenario
p : elasticity parameter

The value of the elasticity parameter is assumed. According to The Standing Advisory Committee on Trunk Road Assessment (SACTRA) (1994), the elasticity parameter is estimated as -0.5 for short term and -1.0 for long term because of the road network improvements.

2.9 Users benefits

The principle rule of a half used to estimate user benefits in this case is generally all road users and specifically the air travellers. Rule of a half calculation will involve two variables: demand and cost. Since this method is an elastic demand estimation, the total demand and cost before and after road improvements are estimated. The rule of a half is then formulated according to the following equation:

$$UB = \sum_{ij}\frac{1}{2}[\![(T]\!]_{ij}^{1} + T_{ij}^{2}[\![\square)(C]\!]_{ij}^{1} - C_{ij}^{2})$$

where

T^{1}_{ij} : total trips i to j by do-nothing scenario
T^{2}_{ij} : total trips i to j by do-something scenario
C^{1}_{ij} : travel cost from zone i to j by do-nothing scenario
C^{2}_{ij} : travel cost from zone i to j by do-something scenario

In SATURN these variables of demand and cost for each zone O-D pair is then created into matrix (X) as the input of user benefits calculation. After the matrices created the formulation of rule of a half it was then codified as the following equation:

$$0.5(X_1 + X_2)\,(X_3 - X_4)$$

3. Results and Discussion

3.1 Network benchmarking and proposed measures

To observe the accessibility to the airport from all origin zones in the network, certain zones need to be set as benchmarks representing trips to the airport from various directions. This aims to identify the common route chosen as well as the access entry junctions used by air travellers to reach the airport with the assumption that the air travellers originate from the zones which are located in the same region and will choose a similar route.

In this analysis there are 9 zones set as benchmarks. These zones represent the trip generations from western, southern, eastern, and northern regions of the airport (Table 2). The route choices to LBIA can be seen in Figure 6.

Table 2. Network benchmarking and proposed measures.

No	O	D	Origin Zone	Access Point Junction	Junction Delay (sec)	Proposed Measures
1	1215	724	Bradford	A657/A658 (Greengates) A658/Bayton Lane	127 84	Adding new lane Priority lane for left turning Signal stage optimization
2	219	724	Bramley	A657/A6120	418	Adding new lanes Changing to signalized junction Signal stage optimization
3	108	724	Leeds City Centre	A660/B6157 (Wood Ln)	153	Adding new lane
4	1401	724	Harrogate	A658/A660 (Pool Bank New Rd) A658/Pool Rd	267 178	Adding new lane Left turning priority lane
5	1240	724	Ilkley	A658/Warrenhouse Ln	10	No significant delay
6	367	724	Kirkstall	A6120/Low Ln	144	Adding new lane
7	734	724	Otley	B6451/A659 (Beech Hill)	174	Adding new lane
8	1263	724	Shipley	A657/A658 (Greengates) A658/Bayton Lane	127 84	Adding new lane Priority lane for left turning Signal stage optimization
9	1600	724	York	A658/A660 (Pool Bank New Rd) A658/Pool Rd	267 178	Adding new lane Left turning priority lane

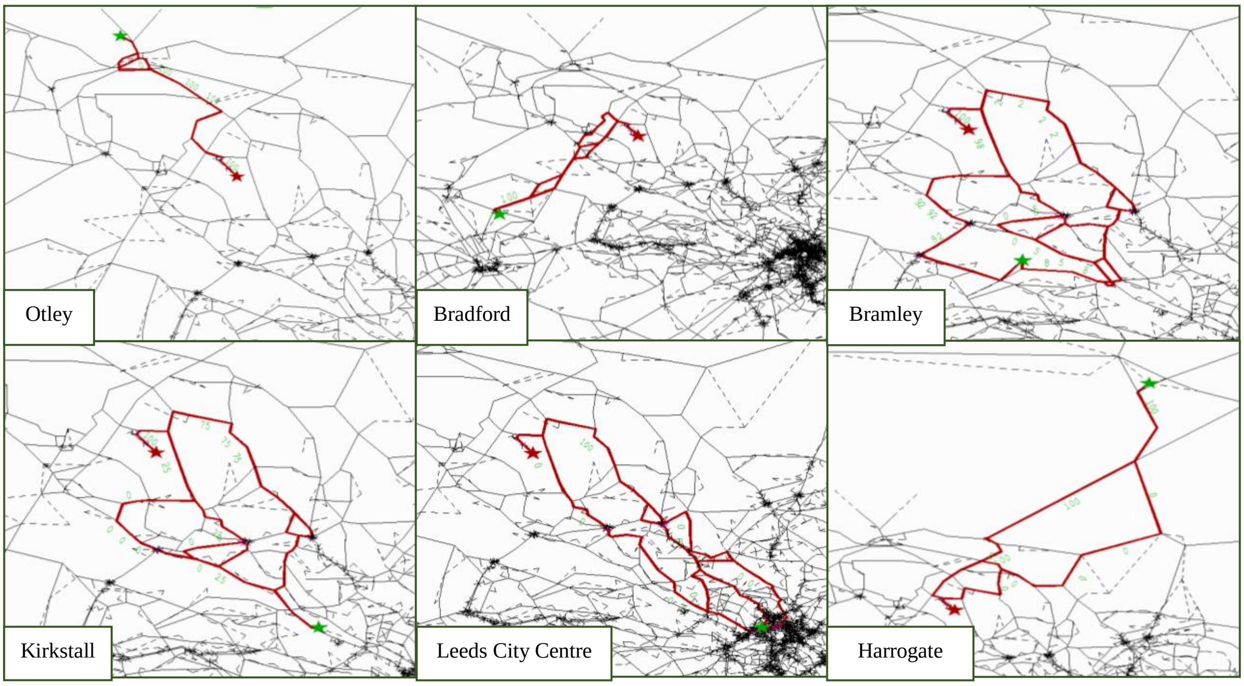


Figure 6. Route choices to LBIA.

3.2 Network improvements

3.2.1 Access from the north

Several junctions along the route from Otley and Ilkley to airport are observed to improve accessibility from the zones north of the airport. From the current network situation, no serious delays in the road access from Ilkley are observed. However, a significant delay of 174 seconds occurs in the access from Otley at the junction B6451/A659 (near Beech Hill) that contributes to the additional travel time from 661 seconds to 774 seconds. This delay time causes a vehicle queue in the north arm that stretches to 10 passenger car units.

In accessing the airport, the air travellers from Otley pass through this junction (node 7623) from the north arm to the south arm side. The north arm has two lanes with one lane to accommodate the southbound traffic and another lane is prioritized for right turn only.

The north arm junction capacity was increased by adding a new lane that shared southbound and right turning flows to relieve the queue and delay. After the improvement, reductions in the time delay and queue at this junction were observed. In the north arm the average delay decreased from 180.5 seconds to 37.5 seconds. The vehicle queue was also removed as there was no longer a queue in the north arm. This increased capacity also managed to reduce the delay time in other arms of the junction.

3.2.2 Access from the west

The trips from the western side of the airport commonly use two main access routes through A658 and A6120 Outer Ring Road. The A658 link is used by air travellers from the Bradford region while the A6120 is used by air travellers from Bramley and its surrounding region. In the road access of Bradford, it is observed that in the A658 link there is a significant delay occurring in A658/A657 Greengates junction. At this junction, the traffic from Bradford towards the airport is delayed by 127 seconds. It also indicates that the traffic from A6157 turning to the right to the airport experienced a delay of 322 seconds.

The V-C ratio at this junction is most likely high because it is reaching 90%. This will affect the junction performance, particularly the increased delay time; therefore, to relieve the delay in this junction certain measures to improve the junction capacity were made. The junction capacity was increased by adding new lanes. From the Bradford side a new lane was introduced to separate the traffic to the airport and the traffic which is turning to the left. Adding the new lane also added capacities to two other arms. After the improvement, the delay time of the airport trips from Bradford was reduced by 80 seconds. The V-C ratio of the junction also decreased from 90% to 80%.

A further measure undertaken for this route to improve the performance of the A658/Bayton Ln junction (node 1377) was to optimize traffic signal stage times. This measure was made by adding the green times in the first stage from 33 seconds to 36 seconds. On the other hand, the green times in the second stage were reduced from 19 seconds to 16 seconds. This measure managed to shorten the delay time in this junction particularly from the west arm (from node 1376) from 84 seconds to 31 seconds. This signal stage optimization showed a positive impact on the traffic in A658; however, for the traffic in Bayton Ln (coming from node 9532 and 7676) there is a slight increase in junction delay.

Another western zone is Bramley. The main access to the airport from Bramley is A6120 Outer Ring Road and A65. Along this route there is the A6120/A657 Rodley

Roundabout that needs improvement because of a higher degree of delay. This delay contributes to the longer travel time during the peak period. In the morning peak period air travellers consume 1498 seconds travel time to reach the airport compared to the inter-peak time when air travellers spend only 982 seconds. The A6120/A657 in SATURN was simulated into several nodes. The most problematic nodes in the roundabout were nodes 9421 and 9422. Node 9421 is a direct access point from Bramley to the airport, while node 9422 gives access to other zones coming from other western zones such as Farsley. The delays at nodes 9421 and 9422 were 418 and 412 seconds, respectively. The delay at node 9421 caused vehicles to queue at around 95 passenger car units (pcu) and in node 9422 it reached 135 pcu.

To relieve the delay time two measurements were implemented. At node 9421, an additional lane towards node 9422 was introduced since the delay time to that direction was very high. While at node 9422 a traffic signal was applied considering the high traffic delay in A6120. On the other hand, the delay from A657 is very low. The implementation of a traffic signal aims to make the traffic flows stay in balance by giving more green times for the flow in link A6120. The improvements of those two measures had a significant impact on the reduction in the junction delay.

3.2.3 Access from the south

From the south side of the airport, the traffic coming from Leeds city centre and Kirkstall tend to use the two most common routes through A660 and A65. The traffic from Kirkstall splits into two routes; 75% of the traffic drives through Spen Ln and then enters Otley Old Rd, while 25% of the traffic chooses the Low Ln and Scotland Ln routes. On the other hand, the air travellers from Leeds city centre drive on the A660 Headingley then enter Otley Old Rd.

These two alternative routes have junction delays in Low Ln/A6120 Outer Ring Road roundabout (node 9431) and in A660/B6157 Wood Ln junction (node 2152). The delays that occur in these junctions are 144 seconds and 153 seconds, respectively.

3.2.3 Access from the east

The air travellers from the east side of the airport, such as Harrogate and York, choose the A658 link to access the airport. In this route there are significant delays experienced by air travellers particularly at the A658/Pool Rd (node 7631) and A660/A658 Pool Bank New Rd (node 585) junctions. The simulated average delay time in these junctions were 178 and 267 seconds.

Introducing a new lane at junction A660/A658 Pool Bank New Rd and splitting the westbound and left turning traffic managed to make a significant reduction in the delay time from 267 to 40 seconds. By the same measure the delay time at junction A658/Pool Rd also decreased from 178 to 67.5 seconds.

3.3 Performance of the measures

3.3.1 Impact on travel time

The performance of the measures to the travel time can be estimated by comparing the amount of reduction in the travel time in the peak period and the travel time gap between AM peak period (before improvement) and the travel time during inter-peak period. This can be expressed through the equation below:

$$Measure\ Impact = \frac{T_p^1 - T_p^0}{T_p^0 - T_{ip}} \times 100\%$$

where

T_p^0 : Travel time at AM peak period before improvement
T_p^1 : Travel time at AM peak period after improvement
T_{ip} : Travel time at inter peak period

It can be observed that almost all the zones experienced a reduction in travel time to airport (Table 3). The range of reductions varied from 40% to 233%. However some zones slightly increased in travel time such as Bradford, Shipley and Ilkley.

Table 3. Impact of the improvement on travel time.

O	D	Origin Zone	Travel Time (sec)		Travel Time After Improvement	Impact (6-5)/(5-4) x 100%
			IP	AM Peak (08.00-09.00)		
1	2	3	4	5	6	7
219	724	Bramley	982	1498	1290	-40,3 %
108	724	Leeds City Centre	1488	1564	1515	-64,5 %
1401	724	Harrogate	1708	1994	1755	-83,5 %
1240	724	Ilkley	1128	1137	1141	+44,4 %
367	724	Kirkstall	1236	1260	1204	-233,3 %
734	724	Otley	661	774	666	-95,5 %
1263	724	Shipley	1059	1277	1279	+0,9 %
1600	724	York	2578	2864	2624	-83,9 %
1215	724	Bradford	919	1117	1120	+1.5 %

3.3.2 Impact on travel cost

The reduction on travel time from certain zones to the airport has an impact on the average generalised cost of travel because time has some value that can be saved. The impact of the scheme on travel cost varies from 48.41 pence to 240 pence. The reduction in travel costs are presented in Table 4.

Table 4. Impact of the improvements on travel cost.

O	D	Zone	Travel Cost (pence)		Travel Cost After Improvement	Gap (pence)
			IP	AM Peak (08.00-09.00)		
219	724	Bramley	1333,68	1873,61	1641,02	-232,59
108	724	Leeds City Centre	1943,82	2019,51	1971,1	-48,41
1401	724	Harrogate	2373,89	2660,26	2420,27	-239,99
1240	724	Ilkley	1692,41	1701,38	1705,55	+4,17
367	724	Kirkstall	1569,7	1650,97	1532,76	-118,21
734	724	Otley	871,49	984,8	876,97	-107,83
1263	724	Shipley	1400,92	1623,1	1640	+16,9
1600	724	York	4276,07	4562,44	4322,45	-239,99
1215	724	Bradford	1197,68	1399,66	1418,05	+18,39

3.4 Appraisal of user benefits

3.4.1 Degree of equilibrium

The delta function (%) variable shows a closeness of the created model to the Wardrop User Equilibrium. The value 0 (zero) shows that the model has reached the equilibrium state and values below 1% are considered to be close to equilibrium state. In this modelling, the delta function was 0.00603 (below 1%), which meant this modelling met the equilibrium state requirement (Figure 7).

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                              FILE -

                 SELECTED CONVERGENCE STATISTICS BY ASS/SIM LOOP N:

Assignment - DELTA FUNCTION (%) / NUMBER OF ITERATIONS
Simulation - FINAL AVER ABS CHANGE IN OUT CFP (PCU/HR) /  NUMBER OF ITERATIONS
Assignment/Simulation LOOP - % LINK FLOWS DIFFERING BY <  1%
Assignment/Simulation LOOP - % TURN DELAYS DIFFERING BY <  1%
VARIATIONAL INEQUALITY % - SHOULD BE > 0
WARDROP EQUILIBRIUM % GAP FUNCTION

 N   Assignment  Simulation    % FLOWS    % DELAYS      % V.I.      % GAP

 1     0.185/26    0.028/21                   27.4                   2.570
 2     0.186/13    0.019/18       28.9        70.1       0.270       0.956
 3     0.138/10    0.022/15       38.2        78.8       0.014       0.506
 4     0.118/10    0.021/14       44.7        83.2       0.036       0.308
 5     0.100/10    0.018/12       51.2        86.0       0.002       0.184
 6     0.069/10    0.021/ 5       56.9        88.3       0.003       0.130
 7     0.050/10    0.030/10       63.6        90.4       0.004       0.096
 8     0.043/10    0.017/ 5       68.2        91.4       0.001       0.066
 9     0.031/10    0.021/ 8       71.8        92.2       0.002       0.065
10     0.028/10    0.014/ 4       73.8        92.8       0.000       0.045
11     0.022/10    0.035/ 7       78.6        93.2       0.001       0.038
12     0.022/10    0.021/ 7       82.1        94.0       0.001       0.035
13     0.017/11    0.013/ 5       82.7        94.3       0.000       0.024
14     0.011/16    0.012/ 7       83.8        94.7       0.002       0.025
15     0.012/10    0.026/ 5       87.6        95.4       0.000       0.016
16   0.00880/17    0.034/ 8       88.5        95.4       0.001       0.037
17   0.00917/17    0.003/ 4       88.2        95.5       0.000       0.023
18   0.00729/14    0.010/ 7       90.6        95.9       0.001       0.015
19   0.00768/10    0.007/ 7       92.9        96.5       0.000       0.014
20   0.00675/11    0.011/ 4       93.2        97.0       0.000       0.0095
21   0.00603/17    0.005/ 7       94.2        97.2       0.000       0.0097

 DISTRIBUTION OF %FLOWS AND %DELAYS AS A FUNCTION OF
 THE CRITICAL DIFFERENCE (PCNEAR):
          <  0.5      1.0      2.0      5.0     10.0     20.0     50.0 %
FLOWS  -    87.85    94.23    97.71    99.33    99.68    99.97    99.98
DELAYS -    97.04    97.24    98.01    99.06    99.49    99.83    99.93
***Pause:  Hit <return> to continue
Enter system command or press ENTER key to restart: _
```

Figure 7. Degree of equilibrium.

3.4.2 Estimated with fixed demand

Following the economic consumer surplus theory, if the price falls, there will be some amount of monetary benefits gained by the consumers. This principle can also be applied in transportation modelling. As the generalised cost of travel decreases, there will be monetary benefits obtained by the road users. The user benefits in transport can be estimated using the fixed demand by multiplying the generalised cost gap reduction by the total trips made by the road users. By this approach it is assumed that the decrease in cost will not affect the travel demand. This assumption is based on the original trip matrix inputted in the SATURN assignment.

The total monetary benefits gained from the scheme estimated with the fixed demand are equal to 150.68 pounds or 0.58 pound per trip.

3.4.3 Estimated with elastic demand

Elastic demand is estimated by including the elasticity parameter (p). In this study the value of 'p' followed the SACTRA (1994) study where short term impact is assumed to be -0.5. The total user benefits gained by elastic demand are estimated to be 153.67 pounds which is slightly higher than the estimation using fixed demand. This slight difference might be caused because of no significant decrease in the generalised cost from all zones generating trips to the airport.

4. Conclusions

The level of accessibility to the airport can be improved by road junction improvements. Certain measures such as adding new lanes, signalized junctions, signal stage optimization, and providing priority left and right turning were implemented to improve the accessibility to Leeds Bradford International Airport. The implementation of these several measures managed to increase the junction capacity as well as reducing the delay and queue in the junctions.

In this research, the junction delay removal has a positive impact on the level of accessibility in terms of shorter travel time and lower generalised cost of travel. From the observation, it was found that the junction improvement in the A660/A658 Pool Bank New Rd and A658/Pool Rd managed to decrease the travel time from York and Harrogate by about 239 seconds and reduce the travel cost by up to 240 pence. However, access from Bradford had a minor negative result in the travel time and cost which increased slightly after the improvement to 3 seconds and 18 pence, respectively. This was possibly caused by the excess of particular junction capacity improvement that causes a higher flow in particular links in this route in which the average speed of traffic flow slightly decreased.

It was also found that the improved network and better accessibility to the airport gave benefits for air travellers because there is monetary value that can be saved from the lower generalised cost of travel. This research identified the total number of trips to the airport during the morning peak period (08.00-09.00 AM) at 261.2 trips. Thus, the total user benefits gained from the junction improvement scheme was estimated to be 153.67 pounds using elastic demand estimation or equal to 0.58 pounds benefit per trip.

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