ASSESSING BUS TRANSPORT REGULARITY USING MICRO-SIMULATION

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ABSTRACT
A wide range of public transport schemes have been proposed and put in practice to improve bus service reliability (e.g. bus lanes, bus priority signals, passenger information systems etc). Central to the successful evaluation of such operational and management measures is to have reliability indicators which are easy to measure and can be used readily by the operators to identify unreliable services and by the traffic commissioners to set standards. Reliability, as a measure of quality of service, is related to the operational characteristics of the public transport system. Passenger's wait time, for example, is much more sensitive to schedule reliability than to service frequency. This paper investigates some of the measures to assess the reliability, such as service regularity and recovery time, of an urban network using a dynamic micro-simulation model (DRACULA). The advantage of using micro-simulation is that one may test various scenarios in an easier, faster and cheaper way than testing them in the field; it is useful for a forecasting approach; some measures of effectiveness impossible to be collected in a field survey may be assessed; it is not necessary to have a great amount of data; and the results may be fast and promptly analysed. In this paper the model results from a test study-case are presented; the significant factors affecting each reliability measure are identified; and the relative merits of the indicators are discussed in a practical identification of public transport service.

RESUMO
Várias medidas têm sido propostas para melhorar a confiabilidade do serviço de transporte por ônibus (faixas exclusivas, prioridade aos ônibus nas interseções semaforizadas, melhor sistema de informação ao usuário etc). O ponto principal ao sucesso de tais medidas operacionais e de desempenho é ter indicadores de confiabilidade que são fáceis de medir e podem ser usados facilmente na identificação de serviços não confiáveis e na definição de padrões pelos operadores. Confiabilidade, como uma medida de qualidade do serviço, está relacionada com as caracteríticas operacionais do sistema de transporte coletivo. O tempo de espera no ponto, por exemplo, é mais sensível à confiabilidade da tabela de horários do que a frequência do serviço. Este artigo investiga algumas medidas para avaliar a confiabilidade, como a regularidade do serviço e o tempo de cobertura, em uma rede urbana usando um modelo de micro-simulação (DRACULA). A vantagem de se usar a micro-simulação é que se podem testar vários cenários de maneira fácil, rápida e barata do que testá-los no campo; é útil nas abordagens de previsão; algumas medidas de eficiência impossíveis de serem coletadas numa pesquisa de campo podem ser avaliadas; não é necessário se ter uma grande quantidade de dados; e os resultados podem ser rapidamente e prontamente analisados. Neste artigo os resultados de um caso de estudo são apresentados; os significantes fatores que afetam cada medida de confiabilidade são identificados; e os méritos relativos dos indicadores são discutidos numa identificação prática de um serviço de transporte coletivo.

1. INTRODUCTION

The passenger's point of view, or quality of service, measures directly the passenger's perception of the availability, comfort and convenience of public transport services. Service coverage, hours of service, passenger loading and transit/auto travel time are, according to the

Transit Capacity and Quality of Service Manual (TCQSM, 2003), easy to measure and have been determined to best represent the passenger's perspective.

According to the Transit Capacity and Quality of Service Manual (TCQSM, 2003) definitions in the Transit Industry are not standardised in the USA and terms as quality of service and level of service carry a variety of meanings. The manual uses the following definitions:

- Transit Performance Measure: a quantitative or qualitative factor used to evaluate a particular aspect of transit services.
- Quality of Service: the overall measure or perceived performance of transit service from the passenger's point of view.
- Transit Service Measure: a quantitative performance measure that best describes a particular aspect of transit service and represents the passenger's point of view. It is know elsewhere as a measure of effectiveness.
- Levels of Service: six designed ranges of values for a particular service measure, graded from "A" (best) to "F" (worst) based on a transit passenger's perception of a particular aspect of transit service.

The manual also states that the primary differences between performance measures and service measures are that service measures must represent the passenger's point of view, while the performance measures can reflect any number of points of view. Service measures should be easy to measure and to interpret in order to be useful to users. Level of Service (LOS) grades are developed only for service measures; however, transit operators are free to develop LOS grades for other performance measures, if those measures would be more appropriate for a particular application.

Bus service reliability is defined as the ability of the service to provide a consistent service over a period of time (Polus, 1978). According to Bates *et al.* (2001), for advertised public transport services, reliability and punctuality (adherence to schedule) are closely related. In the context of the United Kingdom rail passenger transport, reliability is defined according to whether a given train runs; reserving punctuality to denote whether, if the train runs, it arrives at its final destination on time or within a margin thereafter.

Reliability affects the amount of time passengers must wait at a transit stop for a transit vehicle to arrive, as well as the consistency of a passenger's arrival time at a destination from day to day. Reliability encompasses both on-time performance, as well as the regularity of headways between successive transit vehicles.

Transit network designers propose, in practice, network structures that either assume a certain level of service regularity or are especially focused on improving the service reliability. As a key question in a transit network is what is achieved in terms of demand versus the related costs, a quantitative analysis would be more appropriate (Oort and Nes, 2004).

According to Carey (Carey, 1999), measures of reliability and punctuality of scheduled public transport services are important in planning, management, operating and marketing of those services. Methods that can be used to measure reliability are: analytic, simulation and heuristic. Analytical methods are usually practical for only very simple structured systems. Ad hoc or heuristic methods can be easily computed and were discussed by the author in an example of train arrivals and departures at a train station, mainly relating with exogenous and knock-on delays. Simulation methods are very time consuming and require data which may not be available. However, micro-simulation models, like Dracula (Liu *et al.*, 1995), may not require a great amount of data and by using a simple study case with only five runs of the model and various scenarios one can assess the bus transport regularity and operation due to service changes.

Research shows that a better reliable service will attract more transit users. Reliability is defined as a probability that a trip can be made according to the expected trip characteristics, such as, travel time, comfort and costs. Improving regularity and punctuality thus play an important role in making transit service more attractive (Oort and Nes, 2004).

Regularity and punctuality are two different concepts which can be illustrated by an example: if transit service is systematically two minutes late, the punctuality is poor while the regularity is perfect. Punctuality (or adherence to schedule) relates to the deviation from the scheduled arrival and departure times (the headways are of no importance), whereas the regularity is determined by the variation in the transit service headways.

2. MEASURES OF REGULARITY

This paper will focus on two measures of regularity: service regularity and recovery time.

2.1 Service regularity

The regularity of a public transport service is determined by the variation in its headway which is caused by a variation in trip times and boarding and alighting times. Basically, service regularity influences both the supply side and the demand side.

According to Oort and Nes (Oort and Nes, 2004), one way to describe the regularity of a bus transport service is by using the Percentage Regularity Deviation Mean (PRDM), defined in Equation 1. The lower the PRDM, the better the regularity of a bus service.

$$PRDM_j = \frac{\sum_i \left| \frac{TIT_{i,j} - TIA_{i,j}}{TIT_{i,j}} \right|}{n_j} \tag{1}$$

Where: $PRDM_j$ = Percentage Regularity Deviation Mean for stop *j*;
$TIT_{i,j}$ = scheduled headway for vehicle *i* at stop *j*;
$TIA_{i,j}$ = actual headway for vehicle *i* at stop *j*;
n_j = number of vehicles at stop *j*;

For irregular services, the waiting time can be determined in Equation 2 as:

$$TWM = \frac{1}{2} TITM \left(1 + PRDM_j^2\right) \tag{2}$$

Where: TWM = average waiting time;
TITM = average scheduled headway

The perceived Frequency (Fp) is given in Equation 3 as:

$$F_p = \frac{F}{\left(1 + PRDM^2\right)} \tag{3}$$

Where: F = scheduled frequency.

2.2 Recovery time

Transit operators need to maintain punctuality of arrivals and departures at bus stops, but inherent variability in the time along the route may turn this reliability factor difficult to attain. Traffic conditions, passenger activity, weather conditions, maintenance, bus driver's behaviour etc may results in variation of running time which may preclude the punctuality to be attained. One strategy to improve punctuality is to allow more time, referred as "slack or recovery time", in the timetable to allow for the trip to be made as scheduled (Carey, 1998). However, it is well know by transit operators that inserting more time in the schedule will require that the trip takes longer to complete. Carey, 1998, gives an example: suppose bus trips from A to B are time tabled to take no more than 60min, but in practice 10% of buses take more than 60min, although none takes more than 70min. To eliminate lateness suppose one increases the scheduled trip time to 70min. However, one may now find that 15% of the buses take more than 60min, and 5% take more than 70min. Thus, by increasing the scheduled time one can not avoid the buses from running late, as still 5% of the buses are late.

The transit industry is faced with two options: either to impose a "tight" schedule to avoid what they perceive as unnecessary time waste; or to introduce more recovery time in the schedule. Thus, a formal analysis of whether or not to take the two approaches, or what the trade-off cost is, needs to be done and Carey, 1998, provides a useful framework for exploring the problem, although not a complete solution to the problem of managing the recovery time.

Strathman *et al.* (2002), use Levinson's approach (Levinson, 1991) of optimal running and recovery times contending that the running time for a route should be set at a value slightly less than the median/mean in order to avoid the situation where a majority of drivers have to "kill" time to maintain the schedule. The Levinson's proposal is shown in Figure 1.

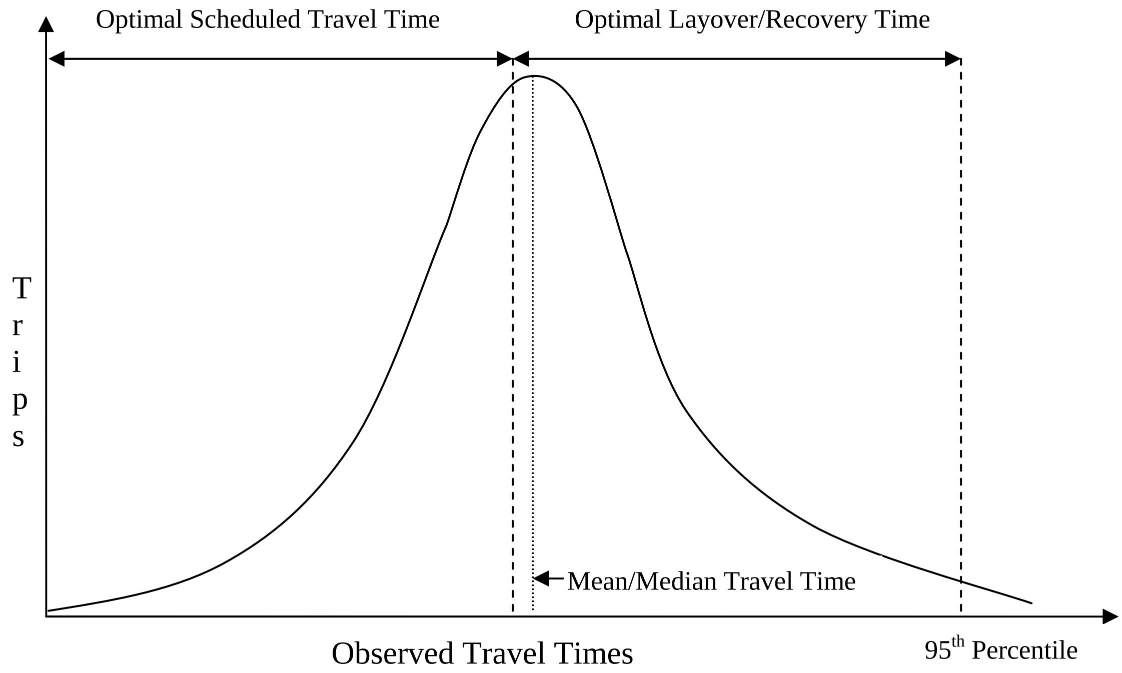

Figure 1: Optimal bus running and layover/recovery times (Adapted from Strathman *et al.*, 2002)

Whether the travel time is set at the mean, the median or some smaller value, the appropriate recovery time is defined as the difference between this chosen value and the travel time associated with the 95th percentile trips in the frequency distribution (so that the 95th percentile trips will have zero recovery time). Strathman *et al.*, 2002, suggest choosing the median observed travel time as the benchmark point in the frequency distribution in order to estimate the optimal recovery time.

According to Strathman *et al.*, 2002, there are three alternatives recovery/layover benchmarks: the first is similar to Levinson's (Levinson, 1991) optimal recovery, or the difference between the median and the 95th percentile travel time; the second is the value associated with the operator's contract requirement (the Tri-Met authority in Portland, OR, USA), or 10% of the median travel time; and the third reflects a "rule of thumb" standard, or 18% of the median travel time, that is generally applied in the schedule development process for the same Tri-Met authority.

3. CASE STUDY: YORK, UK

The city of York is located towards the north of England and is a major tourist attraction with a population of around 177,000 (1998). The bus services being offered to the city by the First Group Company (FGC) are of three types: frequent services: which have one bus at least every twelve minutes; standard services: having a bus every 15 to 45 minutes; and less frequent services: which have one bus per hour or less.

For an in-depth analysis and evaluation of reliability of bus services in York, it was decided to take up one service as the test-route. The selection of the test-route was based on three criteria:

- *Constant Headway Service:* the public transport modelling was carried out in a micro-simulation model (DRACULA) which can only model constant headway services. Although a variable headway service can be modelled by coding it as a separate journey when the headways change, analysing reliability in terms of headway variation and passenger waiting time can be difficult. It was therefore decided to take up a constant headway service.

- *Frequent service having headways of less than 15 minutes*: in cases of frequent service, the average waiting time is half the headway as passengers arrive randomly at the bus stop.
- *Availability of secondary information from the First Group Company:* The FGC collects data on bus arrival times at the bus stops with their "TRACKER" system installed in the vehicles along some of the routes, being Service 4 (Turquoise Line), the test route, one of them. As the availability of these data could help in calibration of the public transport model, it was considered important while selecting the route.

Service 4 (Turquoise Line) runs from the *University* to *Acomb The Green* via the York Railway Station. The route links up residential areas to the railway station and the university. The service has a frequency of eight minutes during the morning peak hour. Figure 2 shows the entire route for Service 4.

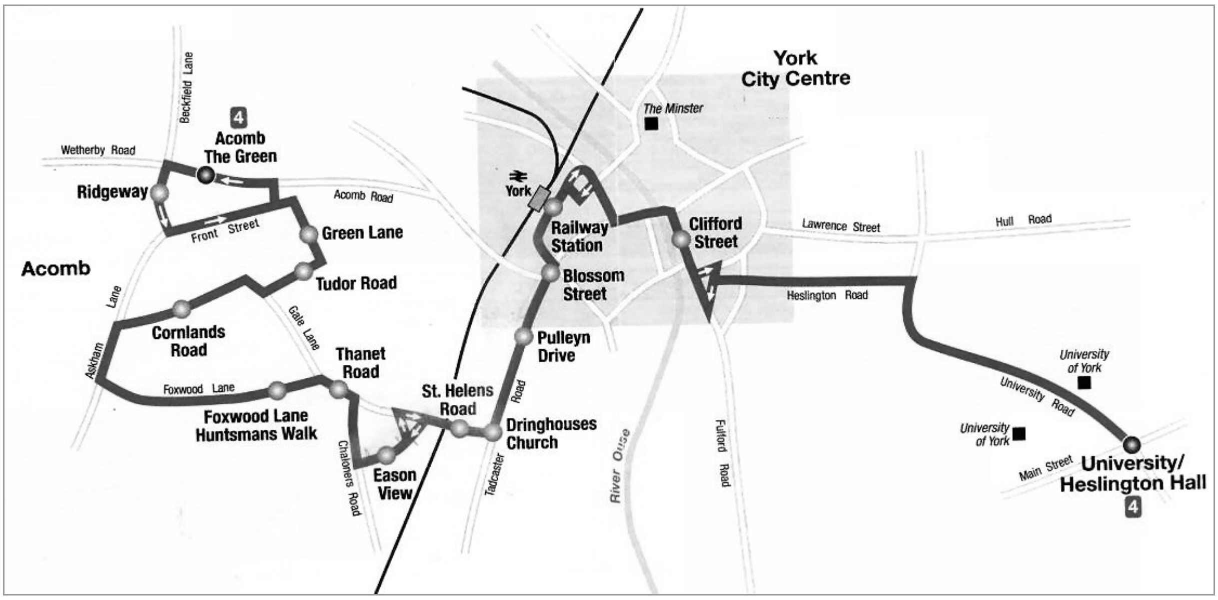

Figure 2: Route for Service 4

The entire route from *The University* to the *Acomb The Green* has a scheduled journey time of 41 minutes and has 35 bus stops. Due to survey time constraints, it was decided to cover a shorter section of the route having a travel time of 10 to 15 minutes and having significant passenger traffic for the detailed study. The information on number of passengers boarding and alighting along the route was collected through a reconnaissance survey. As the morning peak period was being modelled, the route was selected in the predominant traffic direction, which is towards the city centre. A route section from Eason View to the York Railway Station, which is around 3.2km long and consists of ten bus stops, was selected for detailed analysis (refer to Figure 2).

3.1. Data collection

The primary survey of the selected route-section was carried out over three working days, from 21st July (Wednesday) to 23rd July (Friday) 2004, during the morning peak period, from 7:30am to 9:30am. There are 15 scheduled journeys between Eason View and the Rail Station in the peak period and a scheduled headway of 8 minutes. Altogether 21 bus stops were coded (10 in the test route section) so that any variability in the arrival time at the beginning of the test route section could be obtained. The survey was planned such that a representative sample of each of the service could be collected with some overlaps to check the variation. Subsequently, secondary information on the service from the “TRACKER” data was also collected. A total sample of 18 trips was collected in the three days, of which 15 are for each of the peak period services and 3 are overlaps to study the variation in the data collected over different days.

3.2. Input data

The investigation carried out in this paper used the dynamic micro-simulation model “DRACULA” developed at the University of Leeds, UK. DRACULA (Dynamic Route Assignment Combining User Learning and micro-simulation) is a suite of models which represents directly individual driver route and departure time choices and experiences as they evolve from day-to-day, combined with a detailed within-day traffic simulation model of the space-time trajectories of individual vehicles according to a car-following and land changing rules and intersection regulations (Liu *et al.*, 1995). In this study, the car drivers’ route and departure time choice are assumed fixed. The day-to-day variability in network conditions and in driver composition, the later representing variability in modelled driving behaviour and characteristics, is coupled with the traffic micro-simulation part of the model (Liu, 2003) to represent a day-to-day and within-day variability in network congestion and its effect on bus reliability. In the model, the bus operation, in terms of bus service frequency, routes, bus lanes and stops, passenger boarding and demand and bus responsive to traffic signal controls may be directly represented (Liu *et al.*, 1999).

The DRACULA model represents directly the bus service and passenger demand. The bus service is represented in terms of service route, service frequency, the bus stops en-route and the bus lane, if there is one. The passenger demand for bus services represents the flow rate of passenger per hour boarding at each bus stop (Liu *et al.*, 1999). The timetables are not represented in the current version of the DRACULA model; hence it is not possible to model bus holding when a vehicle is ready to leave a key timing point earlier than its timetabled departure time. The passengers’ origin-destination movements are not modelled; hence only passengers boarding are modelled but not passengers alighting the buses. It is therefore not possible to model the passenger route choice behaviour. For the current study, where a single bus route is analysed, this is not a serious problem. Nevertheless, the surveyed data have been analysed in a way they fit in the modelled input data requirement.

The dwell time of buses at the bus stop depends on a constant door opening and closing time plus the time for passengers boarding the bus. The door opening and closing time at each bus stop was assumed initially as 5 seconds and the boarding time per passenger as 8 seconds. The assumed boarding time was higher than the usual 4 seconds because of the timing points along the route, as the model can not take in account the excess wait (in case of buses running ahead of scheduled) at those points. It is also possible to specify different boarding times for categories of passengers: those having a bus pass or smart card, passengers buying ticket on board by tendering exact amount or not etc. Thus, the proportion of passengers in each category needs to be inputted so that the model can calculate the dwell time of the buses based on that proportion.

A random number (NSEED) is introduced into a DRACULA input parameter file (.par) to account for variability in the day-to-day demand. Also, five runs with five different NSEEDs were performed in order to introduce variability in the traffic levels and to test the variability in the model results.

4. RESULTS AND INTERPRETATION

Ten different scenarios, beyond the base-case scenario, and five runs for each scenario were analysed in this research for a stretch of route for Service 4. The scenarios were:

- Base case: the regular service without any change;
- Passenger demand increase: 10%, 15% and 20%;
- Congestion increase in general traffic: 1%, 2.5%, 5% and 10%;
- Boarding time change;
- Bus lane;
- Bus stop type.

For the base case scenario, DRACULA was run according with the data collected for the morning peak period for the test route section (21 bus stops).

For the passenger demand increase scenario, the number of passengers in each stop were increase by 10%, 15% and 20% in the DRACULA bus (.bus) input file.

Increase in congestion for all traffic was tested as 1%, 2.5%, 5% and 10% increase. This was done by introducing the GONZO factor (a SATURN parameter) into the DRACULA parameter input file (.par).

In the boarding time scenario the boarding time for each passenger at a bus stop was changed from the default 8 seconds for the base case scenario to a faster boarding time of 5 seconds into the DRACULA input parameter file (.par).

A bus lane was introduced for a stretch of the route which included 3 bus stops (7 to 9). This was done into the DRACULA bus (.bus) input file.

Finally, for the bus stop type scenario a lay-by was introduced in the stop with the highest number of boarding passengers in order to preclude buses from blocking the general traffic near the bus stop. This was done for bus stop number 1 and introduced into the DRACULA input bus file (.bus).

The outputs from DRACULA were treated in spreadsheets (Excel). The outputs files related to bus performance were: bus travel time (.ptt); passenger delay and passenger dwell time (bus arrival time) (.psn); and passenger delay and passenger dwell time (bus departure time) (.pas). The results were analysed and displayed in tables and figures as shown in the next section.

4.1. Service regularity results

Table 1 shows the service regularity for the 10 scenarios analysed in this research. The PRDM, the TWM and the Fp are calculated according to the above Equations 1 through 3, respectively. Change in frequency is a percent change from the base-case, whereas the change in the level of demand is a change from a 0.36 elasticity value (Oort & Nes, 2004), which states that a change of 1% in the perceived frequency (Fp) results in a change of 0.36% in demand for transit service.

Table 1: Measures of reliability for bus services considering various scenarios (Parameters)

PARAMETERS		PRDM (%)	Average Wait Time (min)	Perceived Frequency Fp (bus/h)	Change in frequency (%)	Change in level of demand (%)
		MEASURES				
Base case		0.60	6.0	8.8	-	(0.36)
Pass. Demand (% increase)	10	0.59	5.9	8.9	1.14	0.41
	15	0.66	6.4	8.4	-4.55	-1.64
	20	0.66	6.5	8.5	-3.41	-1.23
Congestion (% increase)	1.0	0.53	5.6	9.2	4.55	1.64
	2.5	0.63	6.0	8.3	-5.68	-2.04
	5.0	0.52	5.6	9.3	5.68	2.04
	10.0	0.62	6.5	8.8	0.00	0.36
Default Boarding Time (sec)	5.0	0.44	5.2	9.8	11.36	4.09
Bus lane		0.47	5.3	9.6	9.09	3.27
Bus Stop type		0.60	6.0	8.7	-1.14	-0.41

It can be seen from Table 1 that the PRDM is lower for both the default boarding time and for the bus lane scenarios indicating that reducing boarding time and deploying bus lanes can improve service reliability. The PRDM for the bus stop type change has no variation from the base case, which may indicate that a bus lay-by might be good for the general traffic but not for buses. The average waiting time is also lower for the default boarding time and for the bus lane scenarios.

Overall, from Table 1 one can imply that reducing boarding time and providing bus lanes may be the best way to improve bus service reliability. However, the results from the micro-simulation are not clear when there is a passenger demand increase or a percentage increase in congestion as the PRDM and the waiting time do not increase in the same way for these scenarios. The reasons for the misleading results might be that more routes or longer routes should be tested, for the passenger demand scenarios, and a higher percentage increase in congestion should be tested for the congestion increase scenario.

4.2. Recovery time results

In this research, the optimal recovery time was calculated as the difference between the median and the 95th percentile trips in the frequency distribution. Table 2 shows the results from the 5 runs (60 trips in total) from DRACULA for the 10 scenarios tested. The scheduled excess time on the table was obtained by the difference between the scheduled travel time (12.04min) and the median travel time. It can be seen from the Table 2 that the optimal recovery time is always greater than the 10% and the 18% mean recovery times, indicating that the value might have been overestimated. It can also be seen from the results that for two scenarios (20% passenger demand increase and 10% congestion increase) the optimal recovery is too high and the scheduled excess time is negative. This is due to outliers in the frequency distribution indicating that the results from DRACULA are not consistent for these two scenarios.

Table 2: Results in minutes per trip for the various scenarios (Parameters)

PARAMETERS		Mean Travel Time	Median Travel Time	Scheduled Excess Time	95th Percentile	Optimal Recovery Time	10% mean	18% mean
		Minutes per trip						
Base case		11.08	11.00	1.04	14.00	3.00	1.10	1.99
Pass. Demand (% increase)	10	11.45	11.50	0.54	16.00	4.50	1.15	2.06
	15	11.27	11.00	1.04	15.00	4.00	1.13	2.03
	20	14.46	13.00	-0.96	32.00	19.00	1.45	2.60
Congestion (% increase)	1.0	10.77	10.50	1.54	14.00	3.50	1.08	1.94
	2.5	11.03	11.50	0.54	14.00	2.50	1.10	1.99
	5.0	10.83	11.00	1.04	14.00	3.00	1.08	1.95
	10.0	15.05	13.00	-0.96	30.00	17.00	1.51	2.71
Default Boarding Time (sec)	5.0	9.85	10.00	2.04	13.00	3.00	0.98	1.76
Bus lane		10.86	11.00	1.04	14.00	3.00	1.09	1.95
Bus Stop type		10.66	10.00	2.04	14.00	4.00	1.07	1.92

Note: scheduled travel time = 12.04min.

As an example, the frequency distribution for one of the scenarios analysed (Bus stop type: bus lay-by) can be seen in Figure 3.

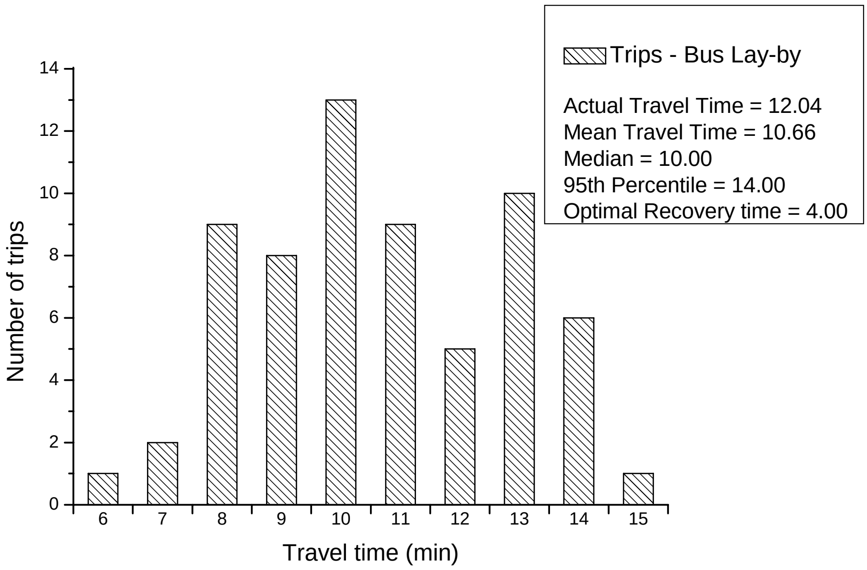

Figure 3: Frequency distribution for the Bus lay-by scenario

5. CONCLUSIONS

This research analysed the bus service reliability using the micro-simulation (DRACULA). Two main measures of reliability were analysed: service regularity and bus recovery time. A small stretch of a bus service was taken from the city of York, UK as a case study. Ten scenarios were analysed in this research and the results have shown that the two measures proposed can be undertaken using micro-simulation.

For the service regularity measure, one can imply that reducing boarding time and providing bus lanes may be the best way to improve bus service reliability. However, the results from the micro-simulation are not clear when there is a passenger demand increase or a percentage increase in congestion as the Percentage Regularity Deviation Mean (PRDM) and the waiting time do not increase in the same way for these scenarios.

For the recovery time measure, the optimal recovery time is always greater than the 10% and the 18% mean recovery times, indicating that the value might have been overestimated. It can also be seen from the results that for two scenarios (20% passenger demand increase and 10% congestion increase) the optimal recovery is too high and the scheduled excess time is negative. This is due to outliers in the frequency distribution indicating that the results from DRACULA are not consistent for these two scenarios.

It is clear from the results that DRACULA performed better for analysing the service regularity than the recovery time implying that a micro-simulation approach could be more useful for analysing the passenger's point of view measure than an operator's one, although more research should be undertaken to validate this assertion.

Future researches should focus on analysing more routes taking in account the whole length of the routes as well. The reason for the inconsistency for some indicators might be in the small number of runs for each scenario. This research used only five runs and a more reasonable number would be much greater, such as fifty runs. Of course, increasing the number of runs would require more time for the evaluation, but modern computers may turn this task less cumbersome. Changes in the current scenarios tested and other different scenarios could also be introduced in an easy way by doing small changes in the input DRACULA files. Of course more data will be require when doing those changes, but this does not preclude the researcher from using micro-simulation and getting prompted results. The advantage of using micro-simulation is that one can always draw conclusions and can have results in a faster and easier way than having field changes and observations.

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