PART 5

Capacity and Quality of Service

Assessing Transit Level of Service Along Travel Corridors

Case Study Using the *Transit Capacity and Quality of Service Manual*

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This paper describes a case study of applying the recent edition of the *Transit Capacity and Quality of Service Manual* (TCQSM) to evaluate the quality of transit service on several travel corridors in an urbanized area. The study focuses mainly on four level-of-service (LOS) measures: service frequency, hours of service, service coverage, and transit–auto travel time. Assumptions are introduced to extend these measures, which are intended for a particular element of a transit system—such as stops and route segments—so that they become applicable for measuring the quality of transit service of travel corridors. An extensive case analysis indicates that all LOS measures are sensitive to various transit planning variables and can be easily calculated with readily available data. The research has also identified a range of issues with the current TCQSM methodology.

The recent edition of the *Transit Capacity and Quality of Service Manual* (TCQSM) (*1*) provides a systematic and comprehensive framework for the evaluation of the capacity and level of service (LOS) for various types of transit systems. One of the major features of the TCQSM is its adoption of a framework that is consistent with the popular and well-accepted document—*Highway Capacity Manual* (HCM) (*2*)—for highway facilities. However, the TCQSM has not yet enjoyed the same level of acceptance and popularity among transit planners and operators as the HCM has among traffic and highway engineers when first introduced. Among the many reasons for this lack of acceptance is the lack of well-documented case studies to demonstrate the potential value of their implementation.

The objective of this paper is to apply the transit LOS analysis methodology proposed by the TCQSM to evaluate the quality of Grand River Transit (GRT) service in the Region of Waterloo, Ontario, Canada.

CASE DESCRIPTION

Situated in southern Ontario, the Region of Waterloo consists of three cities (Cambridge, Kitchener, and Waterloo) and four townships (North Dumfries, Wellesley, Woolwich, and Wilmot). The total population of the region was 460,000 in 2003 and has been estimated to reach 700,000 within 40 years (*3*). Transit services in the region are currently provided by GRT, which was established in 2000 by amalgamating Kitchener Transit with Cambridge Transit. As shown in Figure 1, GRT includes a network of 51 fixed-bus routes, which covers most areas of the three urban centers with an annual ridership of more than 10 million (*4*).

The Region of Waterloo is divided into a total of 519 traffic analysis zones (TAZs), covered by a road network of freeways, arterials, and local streets. For this analysis, demographic data at TAZ level and road attributes (e.g., types, length, and speed) for the year 2001 were obtained from the Transportation Planning Department of Waterloo Region.

To evaluate the quality of transit service in this region, a set of major activity centers were first identified on the basis of population and employment distribution. As shown in Figure 1, 11 major activity centers were selected for this case study, including the University of Waterloo (UW), the Waterloo North Residential (WNR) area, the Kitchener East Residential (KER) area, the Kitchener Transportation Center (KTC), the Kitchener West Residential (KWR) area, the Kitchener South West Residential (KSWR) area, Fairview Park Mall (FPM), the Cambridge North Residential (CNR) area, the Cambridge East Residential (CER) area, the Cambridge Ainsile St. Terminal (CAT), and the Cambridge South West Residential (CSWR) area.

Like other transit systems, GRT is currently providing different services at different times of the day and days of the week with service headways ranging from 15 to 60 min (*5*). Specifically, the following six time periods are considered:

- Weekday morning peak period (06:00 to 09:00);
- Weekday midday (09:00 to 15:00);
- Weekday afternoon peak period (15:00 to 18:00);
- Weekday evening (18:00 to 24:00);
- Saturday (06:00 to 24:00); and
- Sunday (08:00 to 24:00).

LEVEL OF SERVICE ANALYSIS

This section presents the results of an application in determining the LOS of the travel corridors between the 11 activity centers. The analysis focuses mainly on four LOS measures based on performance factors: service frequency, hours of service, service coverage, and transit–auto travel time. Other LOS measures were not considered because they required additional data that were not available at the time of this study.

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FIGURE 1 Grand River Transit and major activity centers in Region of Waterloo, Ontario.

Service Frequency

Service frequency defines the number of times an hour that a user has access to a transit mode. This measure is proposed mainly for evaluating the quality of transit service at a given transit station or stop because only the frequency at a stop can be uniquely identified. For the purpose of this study, service frequency LOS was measured for a travel corridor between two activity centers.

To estimate service frequency for a transit corridor between two activity centers, three issues must be resolved:

1. How to identify the alternative transit paths between two activity centers that are plausible from passengers' point of view,
2. How to determine the transit service frequency for a corridor that is linked by more than one path, and
3. How to account for those itineraries that involve transfers.

To address those issues, the following assumptions were made:

- If two activity centers are connected by more than one transit path, only those paths that do not divert significantly from the shortest one are considered as reasonable. In this study, the identification of reasonable paths was done manually, on the basis of the researchers' visual inspection and judgment.
- If two activity centers are connected by more than one path, the combined service headway is determined based on the combined service frequency of all the reasonable paths. For example, if there are two transit paths connecting the same activity centers with a service frequency of 4 (4 vehicles/h) and 6, respectively, the combined service frequency is 10 vehicles/h with an average headway of 6 min.
- If a travel path consists of two or more transit routes, only the path involving two routes is considered. Furthermore, the route with a longer headway determines the service frequency of the path. For example, if a path involves two routes with the first route running every 15 min and the connecting route having a headway of 30 min, then the service headway for this path is 30 min.

In the subsequent analysis, the researchers first identified all feasible paths and routes connecting the 11 activity centers, and then they checked the schedule tables for headways of individual routes for each of the six service time periods. The combined service headway for each pair of activity centers was then determined, as was the corresponding LOS on the basis of threshold suggested by the TCQSM: A through F, with A the highest level. Table 1 summarizes the LOS analysis results for travel corridors between all activity centers at the morning peak period. From the results, one can observe that there is a wide range of variation in transit LOS in this region, as seen in the performance factor of service frequency. Specifically, the following observations can be made:

- Transit service along the corridors between UW, KTC, and FPM is provided every 3.75 to 5 min via a set of interlining routes, including Routes 7, 8, 12, and 101, and is thus ranked at the top, with an LOS of A. That means that transit users do not need to remember schedules and that transit vehicles will come soon after users arrive at a stop.
- Service frequency along the corridors of KTC with WNR, KER, and KSWR; UW with KER and KSWR; and FPM with WNR and KWR is also relatively high, with an average headway of 10 min, that is, an LOS of B. However, some of the trips (e.g., KTC-WNR, UW-KER) require a transfer at an intermediate point.
- The travel corridors between UW, WNR, and KWR; corridors between WNR, KSWR, and KWR; and KSWR-FPM are covered by a single transit route or path with a headway of 15 min, which provides an LOS of C. Services of the same frequency are also avail-

TABLE 1 Service Frequency LOS on Weekdays, Morning Peak Period

O-D	KTC	UW	WNR	KER	KSWR	KWR	FPM	CER	CSWR	CAT	CNR
KTC		5* A	10 B	10 B	10 B	15 C	3.75 A	N/S F	N/S F	30 D	N/S F
UW			15 C	10 B	10 B	15 C	3.75 A	N/S F	N/S F	30 D	N/S F
WNR				N/S F	15 C	15 C	10 B	N/S F	N/S F	30 D	N/S F
KER					15 C	30 D	30 D	N/S F	N/S F	30 D	N/S F
KSWR						15 C	15 C	N/S F	N/S F	30 D	N/S F
KWR							10 B	N/S F	N/S F	30 D	N/S F
FPM								30 D	30 D	30 D	N/S F
CER									15 C	15 C	N/S F
CSWR										15 C	N/S F
CAT											30 D
CNR											

N/S: no service
*Headway in minutes

able for the corridors between CER, CSWR, and CAT as well as for the corridor of KSWR-KER, except that two combined paths are considered.

- Most service frequency LOS from the residential areas in Kitchener (KER, KWR, and KSWR) and Waterloo (WNR) to other locations is relatively high, ranging from an LOS of D to B, which implies that passengers are able to endure the wait time after they arrive at a stop. However, the same cannot be said for the residential areas in Cambridge with an LOS as low as F through C, and many places have no service at all. In those areas, trip makers have to either walk a long distance to find a bus stop or make at least two transfers to some areas in Kitchener and Waterloo.

Hours of Service

The measure of hours of service is the number of scheduled operation hours in a 24-h period. According to the TCQSM, hours of service is based on those hours when service is offered at a minimum 1-h frequency. Therefore, only those routes that provide service at least once per h are considered. The hours of service can be obtained by subtracting the departure time of the last run from the departure time of the first run and adding 1 h, and then rounding off to nearest hours.

Information on the temporal service coverage of individual routes was derived from the timetables published by GRT, which included the hours of service for each route in different time periods (weekday, Saturday, and Sunday).

Instead of calculating the hours of service available at individual travel corridors and then determining their LOS (which could be done in a way similar as for service frequency), a different approach was used. First, it was decided that the LOS of individual routes be based on their hours of service, and then by using a walking buffer of 400 m around each transit route, the TransCAD was applied to overlay the LOS of all transit routes on the base transit map. For areas that are covered by multiple routes, the route with the highest LOS is assumed. Identification of LOS with overlapping routes can be achieved easily by simply plotting the buffer areas of the routes in descending order of their LOS. Figures 2, 3, and 4 show the hours-of-service measure for weekdays, Saturdays, and Sundays, respectively. The visualizations can facilitate identification and comparison of the LOS of transit service along different travel corridors.

As shown in Figures 2 through 4, the cities of Kitchener and Waterloo (K-W, left side of figure) have a much higher hours of service LOS than the city of Cambridge does (right side of figure). The activity centers located in K-W are well covered by transit on weekdays with an LOS of A, which means that transit service is available for most or all of the day. Even on Sundays, these activity centers are served by transit with an LOS of B.

The K-W and Cambridge transit Route 52 serves as a primary regional connecting link. Although the hours of service LOS in Cambridge is somewhat low in general, customers traveling among the three cities along the central transit corridor still have a high LOS, that is, B.

Service Coverage

Service coverage measures the spatial coverage of the transit system in the study area and is defined by the percentage of transit-supportive area (TSA) that is covered by transit. The TSA is defined as an area where the residential density or job density exceeds a minimum threshold specified by local transit authorities, whereas “transit-covered” area is defined as the area that can be reached from a transit stop or a station within an acceptable walking distance.

Unlike the previous two measures, service coverage is explicitly recommended by the TCQSM to evaluate the systemwide quality of service. This measure is computationally more involved and requires more information than with service frequency and hours of service.

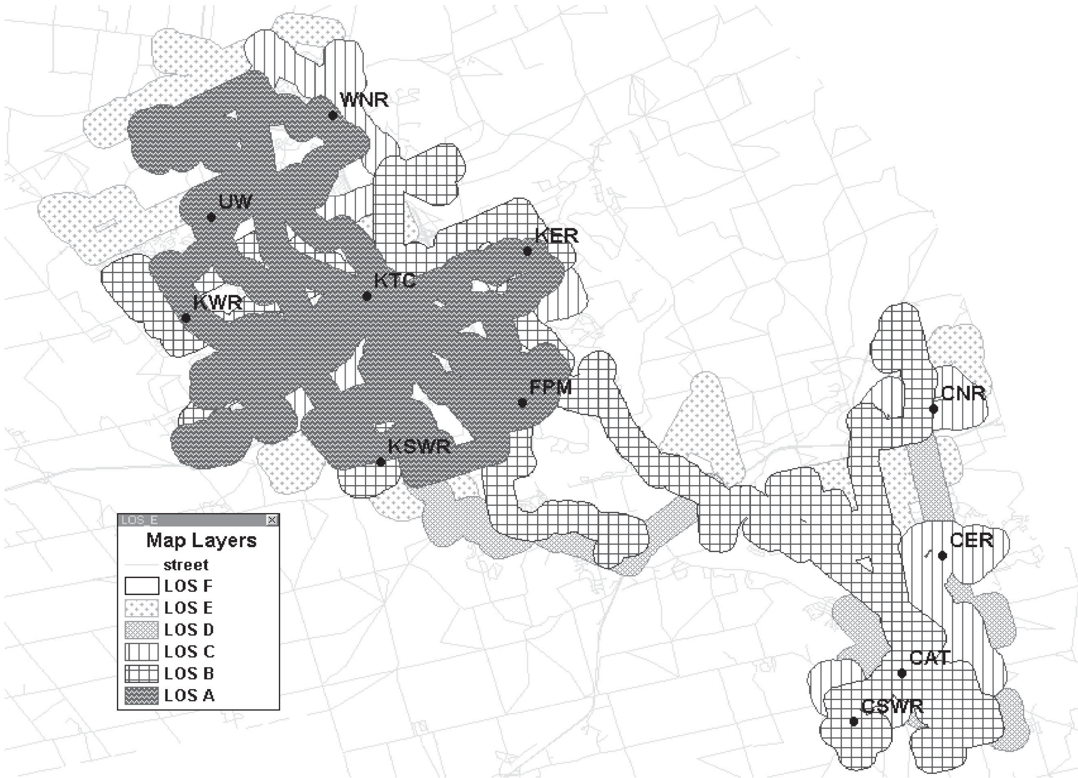

FIGURE 2 Hours of service LOS on weekdays.

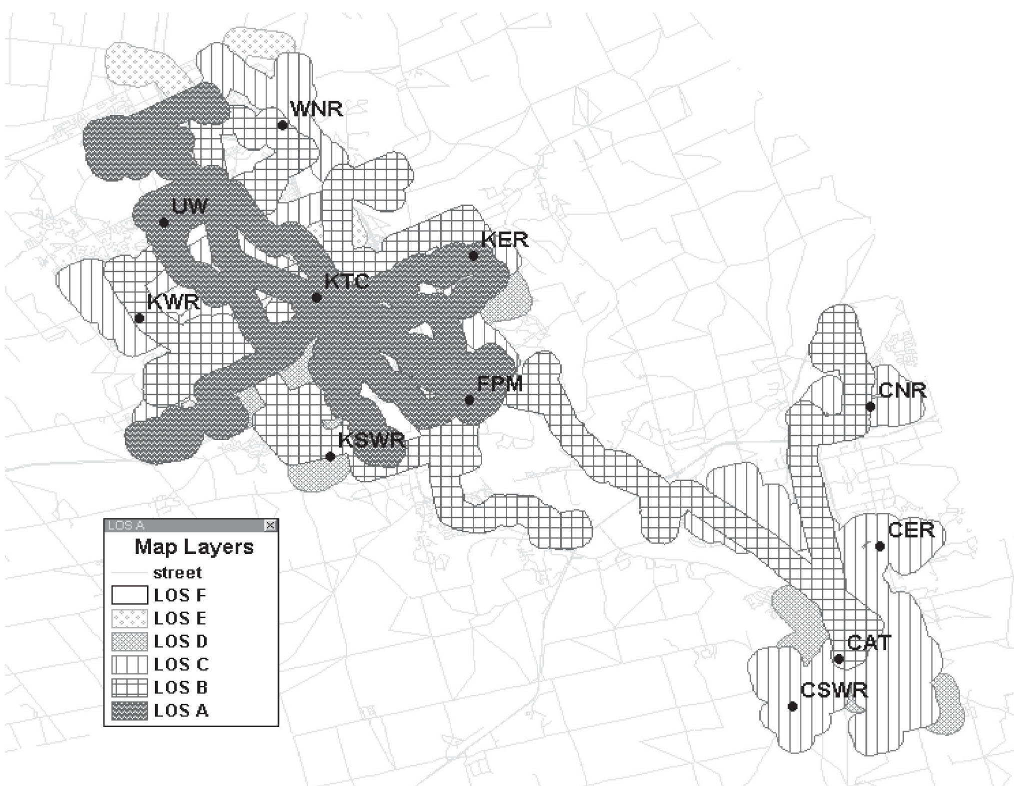

FIGURE 3 Hours of service LOS on Saturdays.

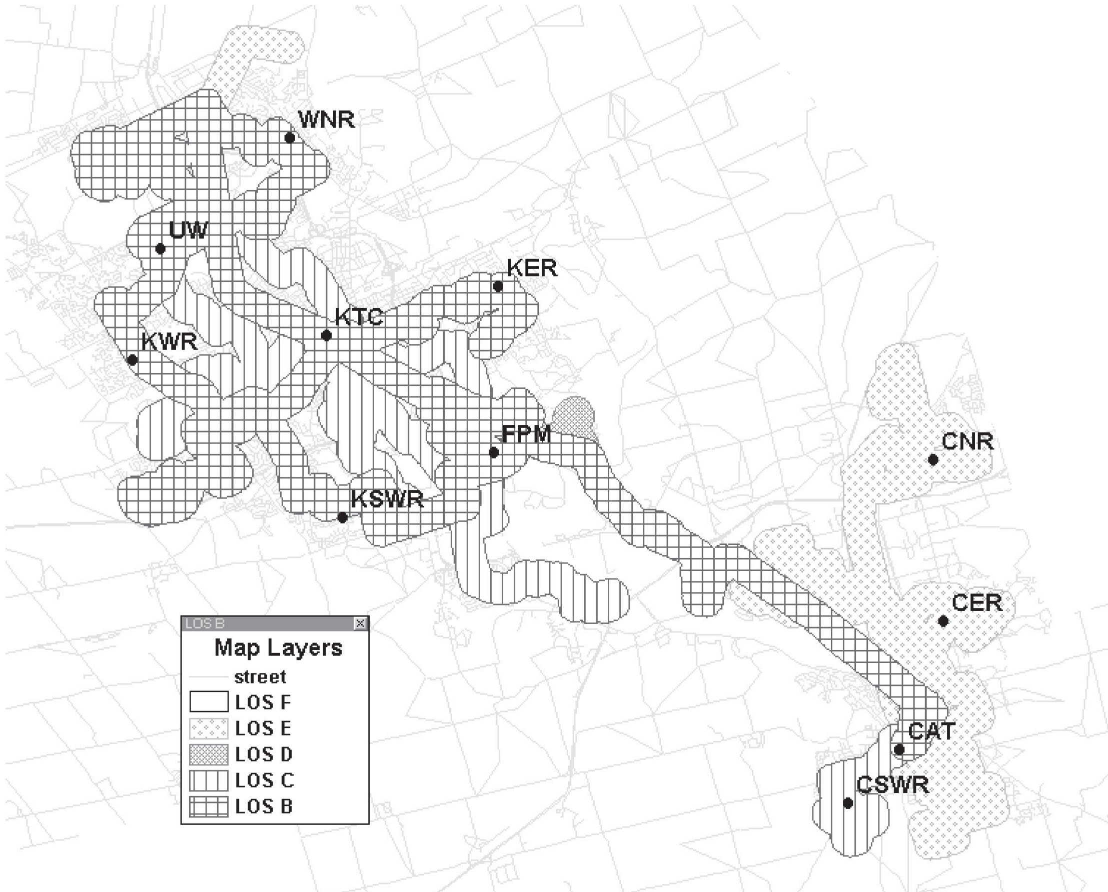

FIGURE 4 Hours of service LOS on Sundays.

Data at detailed geographic resolution (e.g., transportation analysis zones or census blocks) are required, such as population, number of households, and employment. Service coverage also requires detailed information about the transit network, such as configuration of individual transit routes and location of terminals and stops.

In this analysis, the researchers were provided with the 2001 population and employment data of the Region of Waterloo at the TAZ level. Transit routes and stops were entered into TransCAD manually; input data came from the region's street geographic information system (GIS) file and published routes and schedules. As suggested by the TCQSM, a TAZ is considered a TSA if it has an employment density greater than or equal to 10 jobs per gross hectare or a household density greater than or equal to 7.5 units per hectare (*1*). Figure 5 shows the transit-supportive TAZs overlaid with transit routes (morning peak period) in the Region of Waterloo. Two observations can be made from this figure. First, most of the transit-support TAZs are serviced by GRT in the morning peak period. Second, a number of TAZs are not TSAs, but they have transit service. A closer examination found that all those areas have high population or employment values, but with a low population or employment densities.

To determine the service coverage LOS for the study area, first TransCAD was used to identify the TSA. A total of 206 TAZs with a population of 303,661 and an area of 130.03 km^2 were identified as being "qualified" for transit service, as illustrated in Figure 5.

In the second step, the researchers used a 400-m radius to determine the buffer area of all bus stops, and they removed inaccessible areas, such as those separated by rivers, freeways, and so on. Three analysis periods were considered, including the morning peak period on weekdays, Saturdays, and Sundays. The results for the transit-covered area during three periods are shown in Figures 6, 7, and 8.

Finally, all the transit-supportive TAZs overlapped by the transit-covered area were summed to obtain the total systemwide transit-covered TSA. Table 2 provides the final analysis results, which suggest that the service coverage in the Region of Waterloo is quite high, covering all major origins and destinations. Even on Sundays, service coverage reflects at least two-thirds of high-density areas in the region, an LOS of D.

However, the town of Elmira—the second largest population zone, with a population 5,356—has no transit service at all. Although the household density of the town is not high enough for the town to be designated as a transit-support TAZ, many trips generated in this town end in the K-W area.

Transit–Auto Travel Time

The TCQSM suggests that the door-to-door travel time difference between transit and auto can be used to reflect comfort and convenience of a transit system. To estimate the travel times of those two modes, the following assumptions were made, most of which have followed the recommendations in the TCQSM:

- Each activity center is connected to the underlying network through the node that is closest to the center. A uniform walking time of 3 min for transit users is assumed for access and egress.

FIGURE 5 Transit-supportive area.

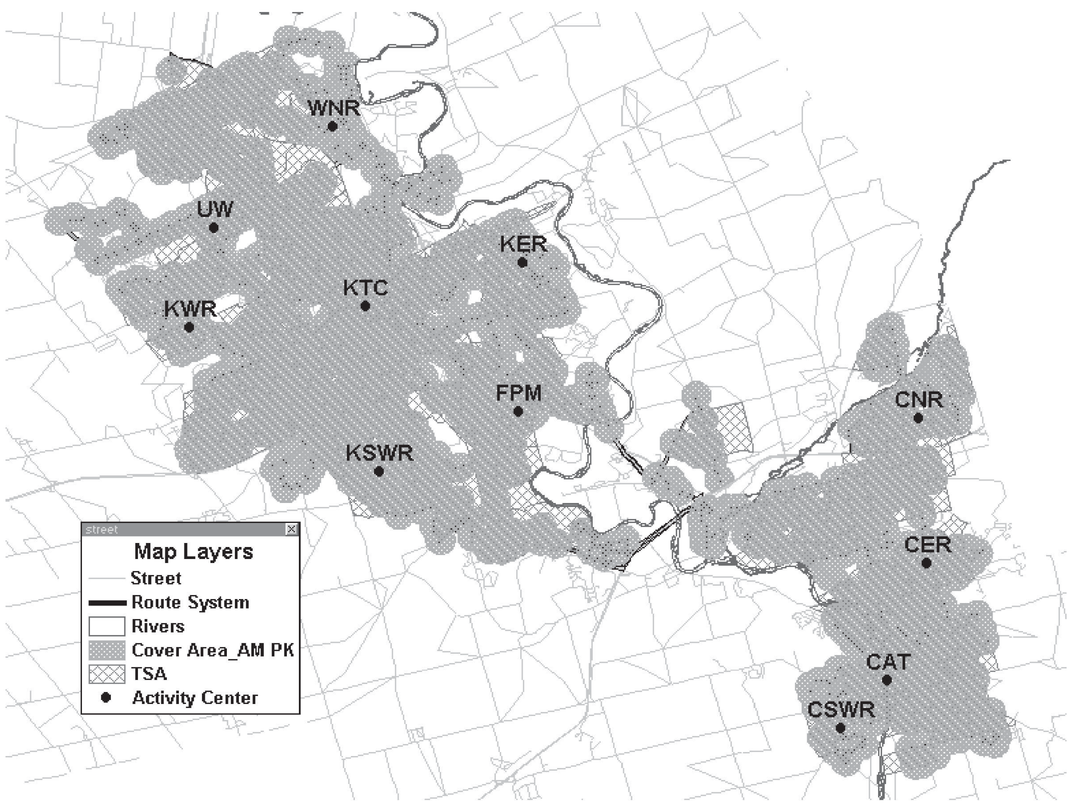

FIGURE 6 Transit-covered area on weekdays, morning peak period.

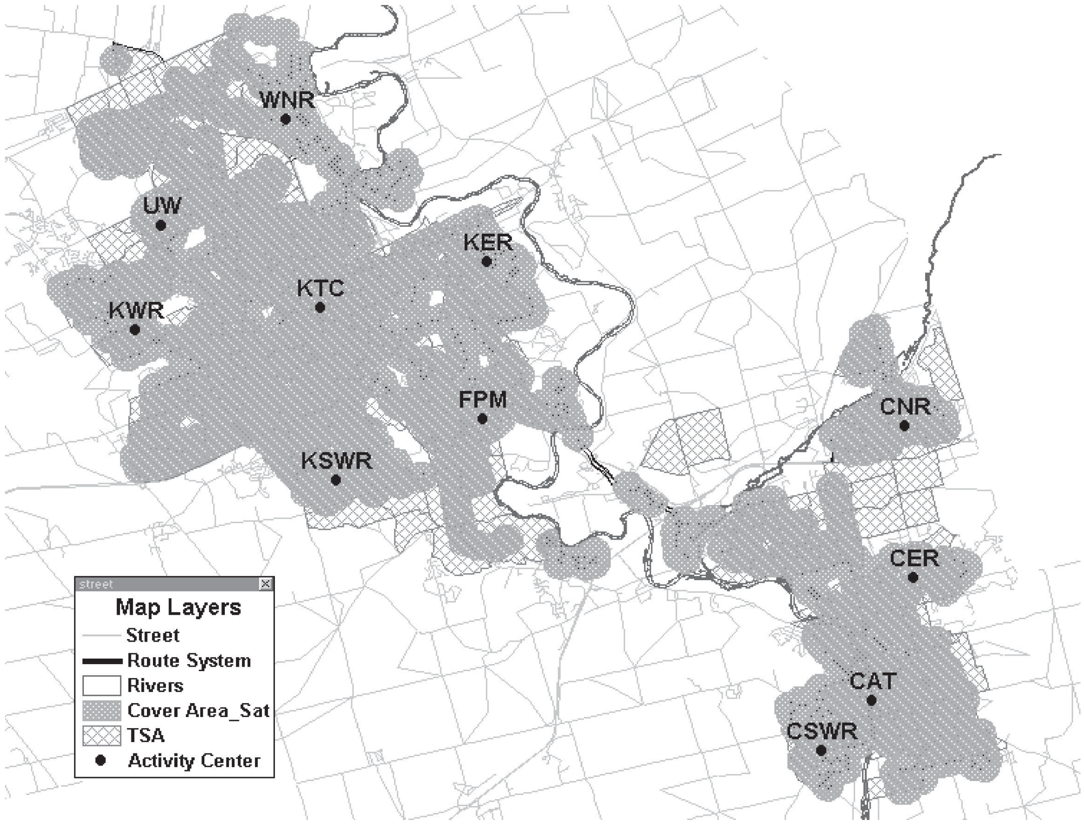

FIGURE 7 Transit-covered area on Saturdays.

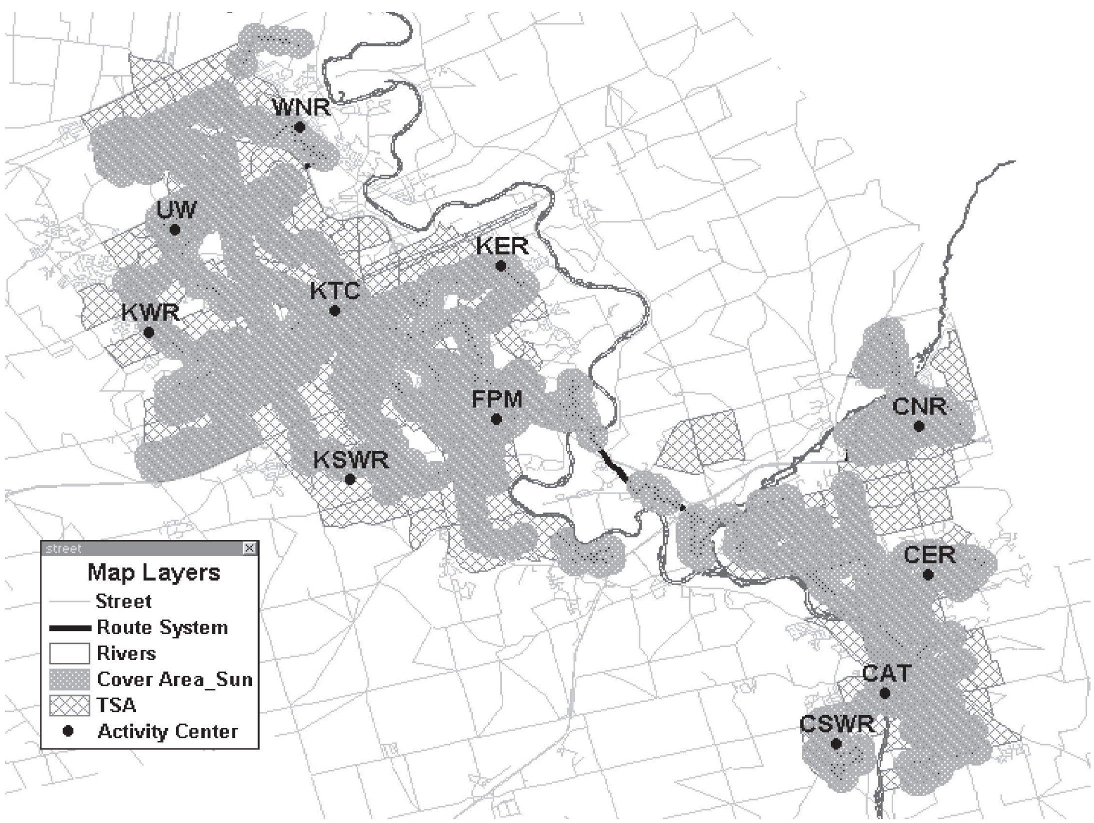

FIGURE 8 Transit-covered area on Sundays.

TABLE 2 Service Coverage LOS

	Weekdays a.m. Peak	Saturdays	Sundays
Transit-supportive area (km^2)	130.03	130.03	130.03
Transit-covered area (km^2)	172.74	146.54	114.91
TSA-covered (km^2)	117.8	105.10	87.12
% of area served	90.6	80.9	67
LOS	A	B	D

- The initial average waiting time for transit is assumed to be 5 min. If transfer is applicable, each transfer is assumed to add 10 min to each trip.
- For automobile trips, a period of 3 min from parking lot to destinations is assumed. Sufficient parking spaces are available; that is, automobile drivers do not need to spend time looking for a parking place.
- Both automobile and transit travel speeds on individual road segments are assumed to be a simple function of the corresponding road speed limits. For automobile mode, speed limits were directly used in calculating shortest path and travel times. For transit travel time, the researchers calibrated the relationship between transit speed and road speed limit on the basis of published timetables. After several trials, it was found that halving road speed limits could approximate transit vehicle speeds along regular transit routes, and travel speeds on express bus routes could be assumed to be 80% of the road speed limits. More accurate estimates can be obtained by either conducting field observations or using a traffic assignment procedure.

On the basis of those assumptions, the total transit door-to-door travel time is found to be the sum of line-haul time, initial waiting time (5 min), access time (3 min), egress time (3 min), and transfer time (10 min each, if applicable). Both automobile and transit line-haul times between the activity centers were calculated using the shortest path method in TransCAD. The final door-to-door travel time differences and the travel time LOS for every two activity centers in weekdays during the morning peak period are given in Table 3.

As with previous LOS results, there is a wide range of variation in the measure of transit–auto travel time along the travel corridors, from an LOS as low as F to a few cases of an LOS of B. The central transit corridor linking UW, KTC, FPM, and CAT enjoys a relatively high LOS of B, while most of the other areas have a low LOS of C or worse. One of the possible explanations for that result is that the Region of Waterloo has a well-developed express highway network (including Highways 7, 8, 86, and 401), which provides speedy automobile travel within the region. Most of the transit routes, however, do not use these expressways, which causes significant differences in travel time between automobile and transit. Furthermore, most places in the region can be reached within 25 min of driving, while transit passengers have to spend almost the same amount of time outside the bus, including walking and waiting.

CONCLUSIONS

In this paper, a case study was presented applying the recent edition of the TCQSM to evaluate the quality of transit service in the Region of Waterloo. The main goal of this study was to investigate the feasibility and limitations of applying the methodology provided by the manual to compare the quality of transit service on various travel corridors within an urbanized region. The following general conclusions could be drawn from this case study:

- The TCQSM methodology for evaluating the LOS of a transit system is straightforward and relatively easy to apply. Data

TABLE 3 Transit–Auto Travel Time LOS on Weekdays, Morning Peak Period

O-D	KTC	UW	WNR	KER	KSWR	KWR	FPM	CER	CSWR	CAT	CNR
KTC		12.5 B	31.4 D	17.6 C	16.2 C	24.6 C	16.5 C	82.3 F	69.9 F	55.5 E	96.8 F
UW	16.3 C		15.1 C	37.4 D	38.4 D	9.5 B	26.2 C	92.0 F	79.6 F	65.2 F	106.4 F
WNR	31.3 D	15.1 C		55.7 E	40.3 D	20.7 C	45.1 E	110.9 F	98.5 F	84.1 F	125.3 F
KER	16.3 C	34.1 D	54.5 E		39.4 D	41.1 D	16.1 C	75.0 F	62.5 F	48.2 E	89.4 F
KSWR	19.2 C	26.0 C	40.6 D	41.8 D		20.6 C	17.4 C	77.2 F	67.2 F	50.5 E	91.7 F
KWR	24.6 C	9.5 B	20.8 C	45.1 E	20.3 C		33.7 D	94.6 F	82.2 F	67.9 F	109.1 F
FPM	14.1 B	22.4 C	50.7 E	23.2 C	15.5 C	32.1 D		57.0 E	44.6 D	30.2 D	71.4 F
CER	79.6 F	85.4 F	113.7 F	87.5 F	78.5 F	96.2 F	57.0 E		33.1 D	18.8 C	9.3 B
CSWR	68.5 F	74.4 F	102.7 F	76.5 F	69.8 F	85.2 F	46.0 E	34.5 D		11.4 B	38.0 D
CAT	53.5 E	59.3 E	87.6 F	61.5 F	52.5 E	70.1 F	31.0 D	19.5 C	10.8 B		23.0 C
CNR	87.1 F	93.0 F	121.3 F	95.1 F	86.1 F	103.8 F	64.6 F	9.3 B	42.7 D	28.3 C	

Numerals signify time difference in minutes.

required for most LOS analyses coincide with those required by other transportation planning processes and are therefore readily available.

- The LOS measures included in the TCQSM cover the important aspects of quality of service concerns by passengers, transit operators, and planners. The four LOS measures evaluated in this study are all informative, and more important, they are sensitive to planning and design variables, such as service headway, route structure, and service span. As a result, they can be used to guide transit agencies to identify problem areas and develop improvement solutions. For example, with those standards, planners can address questions such as the following: How much additional service is required to achieve a LOS of A? Is current transit service coverage equitable to all communities? How much improvement in transit travel time needs to be made, to raise the travel time of a corridor to an LOS of B?
- With the uniform LOS standards, a transit agency can now benchmark the quality of transit service on different travel corridors, or they compare the service with transit systems in other corridors or jurisdictions.
- The transit LOS analysis could be further simplified and enhanced by using GIS tools, which commonly include functionality for performing basic geographic calculations such as buffering, overlapping areas, and shortest path.

The case study has also revealed several critical issues that need to be addressed in future research, specifically the following:

- The TCQSM adopts the approach of using multiple LOS measures to depict the quality of service of a transit system, an approach that somehow departs from the HCM philosophy of using no more than two factors to decide the level of service of a highway facility. The arguments for the HCM approach are twofold. First, there is no single factor that provides an overall reflection of the quality of service of a transit system. Second, it is difficult to combine different types of measures by using weighting factors. The disadvantage of an LOS evaluation system with multiple measures is that it does not allow definite benchmarking of different systems. For example, what could one say about the quality of transit service along a corridor with frequent transit service in the peak period but no service in other periods? How does one compare two transit systems that are ranked high on one LOS measure but low on another, and vice versa?
- In the case of using the existing methodology to assess the LOS of a travel corridor, the results of such analysis depend to a large extent on how the activity centers are defined, because each activity center is represented by a single point (centroid), and all trips are assumed to begin and end at the centroid. The results could therefore be quite different from reality. For example, both automobile and transit travel times between two centers are usually sensitive to the location of the centroids. The actual travel times are different for different trips or travelers, which therefore depend on the distribution of trip origins and destinations.
- In the service coverage LOS analysis, current methodology assumes that only those users who are located within a fixed walking distance (e.g., 400 m for bus transit) from transit stops would use transit service. Past studies, however, have indicated that a number of transit users are willing to walk longer distances to use transit services (*1*). Therefore, that assumption may lead to underestimation of the service coverage in a given area.
- In the travel time LOS analysis, the TCQSM assumes that passengers consider different travel time components (walking, waiting, and in-vehicle) to have same importance. In reality, however, passenger perception on different travel time components is quite different. Walking and waiting are usually considered to be much less desirable than in-vehicle travel time.
- The travel time difference measure is expressed by the absolute transit–auto travel time difference and ignores trip length. As a result, that measure in some degree cannot provide a reasonable explanation on users' behaviors and perception. For example, for the same LOS B on the transit–auto travel time measure, transit users may accept a 10-min difference on a 20-km trip, while rejecting a 10-min difference on a 3-km trip.

To resolve those problems, the researchers have proposed a new performance measure that incorporates the four LOS measures discussed in this paper and characteristics of travel demand. Therefore, that indicator could be used to provide a comprehensive view of the quality of service in a service area or a travel corridor. Details of the methodology are discussed in the paper entitled *A New Performance Index for Evaluating Transit Quality of Service* (*6*).

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