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Level of Service Method for Brazilian Toll Plazas

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Abstract

This paper proposes a method for analyzing level of service of toll plazas. Toll plazas scenarios were developed and evaluated through a qualitative research by toll plaza users from different Brazilian states, and by technical staff from regulating agencies and from the concessionaires responsible for toll plazas operation. The results indicate that queue length at toll booths has a strong influence on the quality of service of toll plazas as perceived by all groups. A level of service classification for toll plazas is proposed, relating the quality perceived by the different groups to the average queue length at toll booths.

Keywords: Level of service, Toll plazas, User perception ;

1. Introduction

Level of service is a measure of quality that describes operational conditions of traffic flow. These conditions are translated into operational parameters directly related to user's perception of comfort and convenience when travelling through different traffic situations. The Highway Capacity Manual – HCM (TRB, 2000) presents scales of levels of service for different components of the road system, however, the HCM does not present a method to evaluate level of service at toll plazas. Moreover, although the concept of level of service is directly related to users' perception of operational conditions, only a few studies seek to identify and represent this perception, including as regards studies involving toll plazas (Washburn & Kirschner, 2006; Choocharukul, *et al.*, 2004; Hostovsky *et al.*, 2004; Pécheux *et al.*, 2004; Pécheux *et al.*, 2000).

Toll plazas may significantly reduce the road capacity, causing traffic jams and delays for the users. The analysis of toll plazas can provide information for decisions as to the management and operation of these systems, directly affecting the service rendered and the users' comfort and satisfaction.

The definition of a scale of levels of service for toll plazas enables (i) the analysis of the impact of changes by before and after studies; (ii) the evaluation of different plazas and operational conditions through standardized indicators; (iii) the inclusion of performance parameters compatible with the expected quality of service in the concession contracts. Thus, technical staff responsible for plaza operation can optimize its functioning, and

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regulating agencies will be able to inspect and enforce the quality of service provided more clearly and efficiently, resulting in improved service to users.

This study proposes a method to analyze levels of service at toll plazas based on the users' perception of quality of service. The method was elaborated based on characteristic data on Brazilian highways and toll plazas, in order to adapt its use to operational conditions prevailing throughout the country.

2. Levels of service at toll plazas

Since there is no specific method dedicated to evaluating levels of service at toll plazas, some studies have been performed on this subject. These studies, however, differ as regards the selection of performance indicators and the scales of levels of service that best represent the operation of these structures.

Outstanding among the main performance indicators used in studies of capacity and level of service at toll plazas, are those involving delays and waiting times in queues (Klodzinski & Al-Deek, 2002), queue length (Van Dijk *et al.*, 1999) and the volume-capacity ratio (Woo & Hoel, 1991; Al-Deek & Radwan, 1995). These indicators, obtained from empirical observations or simulation, are measured with different aggregation levels. Examples of indicators related to delays and waiting times are: (i) waiting time in queue per vehicle (Wanisubut, 1989); (ii) mean waiting time per vehicle (Al Deek & Radwan, 1996), per booth (Gulewicz & Danko, 1995) and for the entire plaza (Polus, 1996; Zarrillo, 1998). Performance indicators involving queue lengths can be represented as: (i) maximum queue length per booth (Zarrillo, 1998) and (ii) mean queue length per booth (Lin & Su, 1994; Gulewicz & Danko, 1995; Burris & Hildebrand, 1996).

Levels of service scales for toll plazas were proposed based on different performance indicators. Significant references on this subject are the studies by Woo and Hoel (1991), Lin and Su (1994) and Klodzinski and Al–Deek (2002).

Woo and Hoel (1991) statistically correlated the volume–capacity ratio to the density in arrival and departure areas of the plazas, concluding that the V/C ratio could be estimated from the density values. The authors found that there was a statistical similarity between the V/C ratio and densities shown in the HCM for levels of service on highways and the same ratios obtained at the plazas in the study. Density was then chosen as a performance indicator and the scale proposed was similar to that adopted by HCM for highways.

The scale proposed by Lin and Su (1994) uses the mean queue length at the booths and the mean time in the system as performance indicators. The mean times used to define the scale were based on the values of delays indicated in the Highway Capacity Manual for Taiwan Area" for levels of service at intersections with traffic lights.

Klodzinski and Al-Deek (2002) adopted the individual delay suffered by drivers when crossing a road section where there is a toll plaza as a performance indicator. Mean times of service were defined based on surveys done in the United States and Canada. The definition of levels of service was based on comparing delays in toll booths with delays at intersections with traffic lights according to criteria established by the HCM 2000.

The methods of Woo and Hoel (1991), Lin and Su (1994) and Klodzinski and Al-Deek (2002) attempted to represent the discomfort and inconvenience of users when travelling through toll plazas using different measures of performance. However, none of these studies tried to pick up the perception of toll plaza users about the analyzed operational conditions.

The methods proposed to qualify levels of service at toll plazas presented in the literature are heavily influenced by the methodologies established by HCM. Authors seek to establish analogies with the methodologies to evaluate highways or interrupted traffic flow conditions, such as signalized intersections. Toll plazas, however, present different operational conditions from highways and are mostly inserted in environments different from intersections with traffic lights. The users probably do not evaluate the level of service according to the same criteria. Furthermore, local experience should strongly influence the conditions considered acceptable by the users.

Another important point to be considered is the method practicality. Methods based on delays and travel times require a reasonable data collection effort. The need to collect delays and travel times may impair the method frequent use. The proposal presented in this article adopts mean queue length and percentage of trucks on traffic flow as performance indicators. These indicators have three important qualities: they are robust, simple to collect and easily understood by users.

In order to achieve broad representativeness of different stakeholders of Brazilian toll plazas, surveys were applied to users from different regions of Brazil, technical staff responsible for operating toll plazas, and technical staff from regulatory agencies.

3. Fundamentals of the method

The method proposed in this study is based on users` perception of quality of service at toll plazas. The quality of service at toll plazas may involve several elements, such as: (i) user`s waiting time in the queue; (ii) plaza infrastructure conditions (quality of the pavement, width of lanes, number of booths, lighting, etc.); (iii) the way the user is treated at the booths (speed, courtesy, etc) and (iv) informative signs about fare values and forms of payment. For this method the quality of service perceived at the plazas involves only the factors that interfere in the users' waiting time in the queue. Other possible factors related to perceived quality at the plazas were not taken into account.

The quality perceived by users in different traffic situations at toll plazas was obtained by qualitative research. Research on the respondents' perception was performed by presenting videos obtained from scenarios built with a traffic simulation model and controlled parameters.

The qualitative research was applied to toll plaza users from different Brazilian states, selected to provide a sound representation of the Brazilian toll system. The selection criterion resulted in the states of Rio Grande do Sul, São Paulo, Santa Catarina and Rio de Janeiro. According to the Brazilian Association of Highway Concessionaires (ABCR), these states concentrate 190 of the 293 toll plazas operating in Brazil.

The same qualitative research was also applied to technical staff from regulating agencies connected to the government, and technical staff from the highway concessionaires responsible for plaza operations. The research performed with technical staff from regulating agencies and from the concessionaires was not segmented by state, since the population of technical staff working in the country is a small universe compared to the universe of toll plaza users. The qualitative research applied to plaza technical staff and users enabled the comparison of the perceptions of the different stakeholders involved in the toll system about operational quality at toll plazas.

4. Qualitative research on the perception of quality of service at toll plazas

The research planning process involved the decision about the intervening factors in the quality perception at toll plazas, the limit values for these factors, definition of scenarios and the survey sizing. The definition of the scenarios that composed the interviews was based on a design of experiments.

The factors considered in the scenarios were the percentage of trucks in the flow, the number of booths at the plazas and the mean queue lengths at the booths. The "percentage of trucks in the flow" is traditionally included in methods to analyze the capacity of road systems. The presence of trucks at toll plazas may influence the quality perceived by users in two ways: (i) trucks are larger, resulting in longer queues at the booths; and (ii) their operational characteristics leads to higher service times and a consequent lower performance compared to cars. The "number of booths" is directly related to the area available for maneuvers on arrival at the plazas. The "mean queue lengths at the booths" is the performance indicator resulting from the relationship between demand and the processing capacity of the booths. Queue lengths are directly proportional to the waiting times and to the delays experienced by users, influencing the perception of quality of service at toll plazas.

In order to ensure the applicability and validity of the method, the definition of limit values of the three factors was based on operational conditions characteristic of Brazilian highways and toll plazas.

The maximum value of the factor "percentage of trucks in the flow" was defined based on the characterization of heavy vehicles traffic on São Paulo highways. Analyzing data from the Transport Regulating Agency of the State of São Paulo, studies concluded that, to evaluate the impact of heavy vehicles on traffic, percentages of up to 60% of trucks have to be considered. São Paulo roads carry the heaviest traffic in the country. The maximum percentage of trucks adopted in the scenarios was, therefore, 60%.

The definition of the maximum number of boots was based on information about the layout of toll plazas located in the states of Rio Grande do Sul, Santa Catarina, Parana, São Paulo, Rio de Janeiro, Minas Gerais, Ceara and Bahia, which comprised 70% of the total number of plazas in the country. The minimum level of the factor "number of booths" was defined as 3 booths and the maximum was equal to 18 booths.

The factor "mean queue length at the booths" was measured in meters and not in number of vehicles, as in the study by Lin and Su (1994). This measure is easier to monitor in practice. Queue lengths acceptable limits can be defined by road marks in the pavement, and this indicator can be easily monitored by camera systems or other automatic data collection devices. This parameter was considered the most appropriate to represent the influence of demand on the perception of quality of service at toll plazas. Furthermore, this variable has been used as a performance parameter in concessions contracts of the Brazilian National Agency of Terrestrial Transportation (ANTT) to regulate the service provided by concessionaires. The maximum queue length considered in the scenarios was 60 m, equivalent to about 10 cars in queue.

The qualitative research was planned by a design of experiments. The levels of the controlled factors in the scenarios represent the input variables of the survey. The response variable of the experiment was the "scenario score" which ranged from 1 to 7, representing the quality perceived in relation to the traffic situations presented.

The dimension of the research was defined by a second order composed project. The levels adopted for the different factors were:

- Percentage of trucks in the flow: 0%, 10%, 30%, 50% and 60%;
- Mean queue lengths at booths: 0 m, 10 m, 30 m, 50 m and 60 m;
- Number of booths at the plaza: 3, 6, 10 and 18.

The result of specific combinations of the factor levels, led to 15 research scenarios (see Table 1).

5. Elaboration of the scenarios for qualitative survey

The research scenarios were constructed with the traffic simulation model VISSIM, version 4.30-05 (PTV, 2006). Four networks were modeled, representing 3, 6, 10 and 18-booth plazas. The geometric characteristics of simulated toll plazas were defined based on the survey about the Brazilian toll plazas mentioned in item 4.

Flow characterization was based on data from the *Manual of Traffic Studies of the National Department of Transport Infrastructure-DNIT*. Vehicles of the simulation scenarios were divided into three classes: (i) cars; (ii) light trucks and (iii) heavy trucks. Light trucks were considered those with 2 and 3 axles, maximum length of 14 m, and maximum gross weight of 23 tons. Heavy trucks were considered those with 5 and 6 axles, maximum length of 19.8 m and maximum gross total weight of 57 tons. The truck category was divided into two classes due to the impact of this type of vehicle on queue lengths at the booths.

In all modeled scenarios, the service times at toll booths were compatible with manual charging systems, and all booths were open to traffic.

The calibration of the toll plazas simulation models was based in the adjustment of the distance between vehicles in the queues, decelerations and desired speeds. Data from acceleration, deceleration and travel times at toll plazas were based on a study for the state of São Paulo.

6. Research application

The simulated scenarios were presented to respondents through the visualization module in a third dimension of VISSIM software (PTV, 2006). The duration of the videos representing each scenario was approximately 25 seconds.

The research was applied to users from different Brazilian states, and to technical staff of the concessionaires and regulating agencies. The research was structured into 3 questionnaires, each containing 5 of the 15 scenarios prepared. The questionnaires were applied via internet in order to reach the greatest possible number of respondents from all groups.

The respondents' perception of the scenarios quality of service was obtained by attributing concepts ranging from "Extremely bad" to "Excellent", as shown in Figure 1. The respondents were instructed to mark the alternative which most closely approached their degree of comfort and satisfaction regarding the traffic conditions encountered in the images, if they were travelling in the toll plazas shown in the videos.

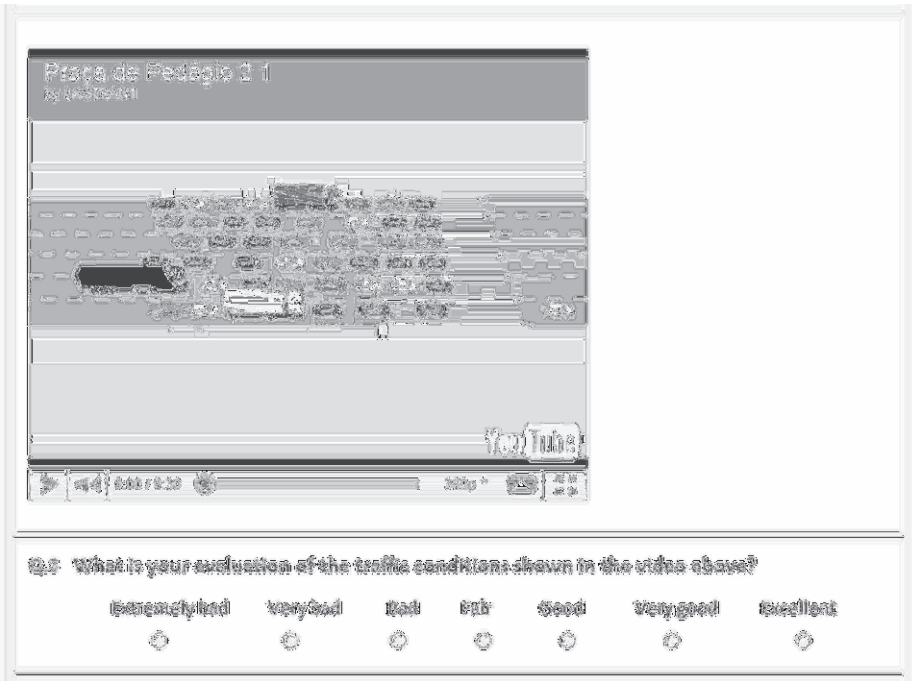

Figure 1: Fragment of the questionnaire used to evaluate the scenarios

The users samples comprised: (i) 142 toll plaza users from the state of Rio Grande do Sul; (ii) 55 from the state of Santa Catarina; (iii) 197 in São Paulo; and (iv) 88 toll plaza users from Rio de Janeiro. The samples consisted of users from different age groups, with a minimum age equal to 18 years. Gender and level of schooling of the interviewees were not considered important factors for sample stratification.

The sample of concessionaires technical staff comprised 21 engineers or technicians directly connected to toll plaza operation. Currently, in Brazil, there are about 50 concessionaires affiliated to the Brazilian Association of Highway Concessionaires (ABCR). Due to the small number of technical staff working at the Brazilian plazas, the sample size was also small, so that it was impossible to perform any stratification. The same occurred with technical staff from regulating agencies. The sample of technical staff from government-owned regulating agencies surveyed comprised 29 individuals. They are responsible for supervising, inspecting and auditing the concession contracts of state and federal highways, and also for the evaluation of concessionaire performance.

7. Analysis of the results of the qualitative survey

The concepts attributed to quality of service of the scenarios were transformed into scores, that comprise the experiment response variable. Scores range from 1, corresponding to Extremely Bad, to 7, corresponding to Excellent. The score of each scenario was obtained from the mean of the assigned scores by interviewees. Atypical values were discarded. The means of the scenarios' scores are shown in Table 1.

The analysis of Table 1 indicates that traffic composition tends to have little influence on the scores assigned to the scenarios. The small influence of the composition of traffic on the quality perceived by users and technical staff can be verified by comparing the scores of scenarios that present the same number of booths and queue length, but variable traffic compositions, as in the case of scenarios 2 and 6, 1 and 5 and of scenarios 4 and 8.

It was also observed that the numbers of toll booths have small influence on the scenarios scores. The small influence of the number of booths on the quality perceived by users and technical staff can be verified comparing the scores of scenarios 1 and 3, 2 and 4 and scenarios 6 and 8.

Table 1 also indicates that the scores assigned to scenarios tend to reduce rather significantly when queue lengths at the booths increase. This reduction is noticed in the results of all surveyed groups.

Table 1. Mean scores attributed to the research scenarios

Scenario	% of trucks	Nr. of booths (n)	Queue length (m)	Scores of scenarios according to the different groups					
				Toll plaza users				Technical staff	
				SC	SP	RJ	RS	Regulators	Operators
1	10	6	10	4.33	4.15	4.67	4.42	4.71	4.25
2	10	6	50	2.50	2.96	3.55	2.50	3.00	3.80
3	10	18	10	4.63	5.00	5.69	4.88	5.29	4.50
4	10	18	50	3.00	2.19	3.08	2.32	3.75	4.00
5	50	6	10	4.83	4.89	5.09	4.88	5.00	4.75
6	50	6	50	2.38	2.60	2.77	2.53	3.50	4.40
7	50	18	10	5.44	5.44	5.92	5.58	5.57	5.50
8	50	18	50	3.00	2.74	3.73	2.63	3.00	4.40
9	0	10	30	2.50	2.68	3.23	2.94	2.86	3.00
10	60	10	30	3.56	3.30	4.08	3.58	4.50	5.40
11	30	3	30	3.33	3.15	3.45	3.63	3.43	3.25
12	30	18	30	2.75	2.92	3.69	3.18	4.50	5.60
13	30	10	0	6.44	6.78	6.67	6.89	6.71	6.50
14	30	10	60	2.50	2.78	3.64	2.69	3.00	3.60
15	30	10	30	2.88	2.72	3.38	2.94	3.43	3.00

It is also possible to notice in Table 1 that scores assigned by users of plazas in the states of Santa Catarina, São Paulo and Rio Grande do Sul are very similar. The scores assigned by users of plazas in Rio de Janeiro are generally higher than those assigned by users from the other states. The scores assigned by staff from operating companies are usually higher than those assigned by the other groups.

8. Modeling the perception of quality of service

Models of perception of quality at toll plazas were estimated with the survey data. The modeling was performed using StatGraphics v.15.2.06 software (StatPoint, 2005), and the equations which best represented the data were of the negative exponential type obtained by non-linear multiple regression. The effect of the variable "number of booths at the plaza" did not prove significant in any of the cases, and the variable was removed from the models. The models reproduce values for "Scenario Scores", which range from 1 to 7, obeying the contour limits established in the survey. The general form of the equation obtained to represent the perception of quality of service of the different groups is:

$$\text{Scenario Score} = 1 + 6{,}0 . e^{-\left\{\left(\frac{QL}{a}\right)^{b} . \left[1-\left(\frac{\%T}{c}\right)\right]\right\}} \quad (1)$$

where "QL" represents the variable "Mean Queue Length at the booths" [meters];
"%T" represents the "Percentage of Trucks in the flow" [decimal value];
a, b and c are the adjustment coefficients of the model for each group.

Equations 2 to 5 show the models of quality of service estimated for users from the states of Rio Grande do Sul, Santa Catarina, São Paulo e Rio de Janeiro. Coefficients of determination indicate very good adjustments to data.

$$\text{Scenario Score}_{RS} = 1 + 6.0 . e^{-\left\{\left(\frac{QL}{26,8}\right)^{0.710} . \left[1-\left(\frac{\%T}{2,47}\right)\right]\right\}} \qquad R^2 = 96.2\% \quad (2)$$

$$\text{Scenario Score}_{SC} = 1+6.0.e^{-\left\{\left(\frac{QL}{24,2}\right)^{0.636}.\left[1-\left(\frac{\%T}{2,17}\right)\right]\right\}} \qquad R^2 = 91.0\% \tag{3}$$

$$\text{Scenario Score}_{SP} = 1+6.0.e^{-\left\{\left(\frac{QL}{25,2}\right)^{0.659}.\left[1-\left(\frac{\%T}{2,62}\right)\right]\right\}} \qquad R^2 = 92.2\% \tag{4}$$

$$\text{Scenario Score}_{RJ} = 1+6.0.e^{-\left\{\left(\frac{QL}{42,5}\right)^{0.615}.\left[1-\left(\frac{\%T}{3,22}\right)\right]\right\}} \qquad R^2 = 84.0\% \tag{5}$$

The model of the perception of technical staff from regulating agencies is shown in equation 6. This model´s coefficient of determination (R^2) was 86.1%.

$$\text{Scenario Score}_{Reg} = 1+6.0.e^{-\left\{\left(\frac{QL}{38,3}\right)^{0.590}.\left[1-\left(\frac{\%T}{2,10}\right)\right]\right\}} \tag{6}$$

Equation 7 presents the model of the perception of quality of toll plazas of the technical staff from operating companies. This model obtained the lowest coefficient of determination: R^2 was equal to 60.6%.

$$\text{Scenario Score}_{Op} = 1+6.0.e^{-\left\{\left(\frac{QL}{51,3}\right)^{0.236}.\left[1-\left(\frac{\%T}{1,10}\right)\right]\right\}} \tag{7}$$

The models of the quality of service for users from the states of Rio Grande do Sul, Santa Catarina and São Paulo (Equations 2, 3 e 4) presented very similar coefficients of adjustment “a”, “b” and “c”, indicating that users from these states have similar perceptions about the expected quality of service at toll plazas.

Sensitivity analysis may help to clarify the influence of the variables in the perception of quality at toll plazas. Figure 2 and Figure 3, for example, show the sensitivity graphs of the model that represents the perception of plaza users in the state of Rio Grande do Sul.

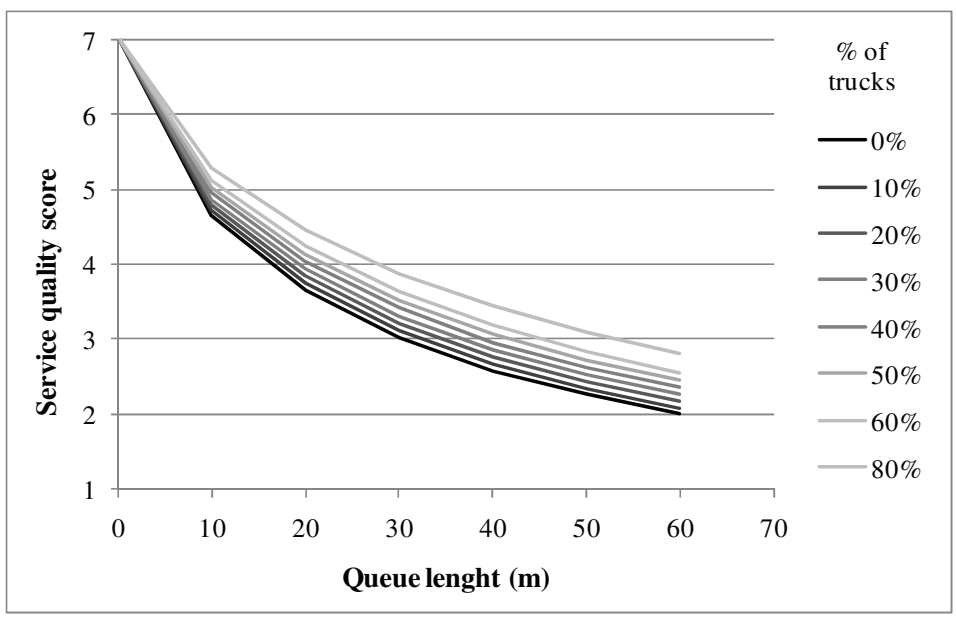

Figure 2: Sensitivity graph of quality of service concerning the queue length and percentage of trucks

The “Queue Length” has a very strong influence on the variable “Scenario Score”. The scenario score drops from 7 to about 2 when the queue increases from 0 to 60 m, as shown in Figure 2.

The effect of the variable “Percentage of Trucks” is relatively low, but significant. The quality perceived in the plazas improves by about 0.1 point (considering the scale of 1 to 7), with the addition of 10% to the percentage of

trucks in the flow, according to Figure 3. This improvement can be attributed to the fact that, for a given queue length, the user prefers this queue to contain trucks, because this means a smaller number of vehicle in the queue and less payment operations, resulting in a shorter waiting time.

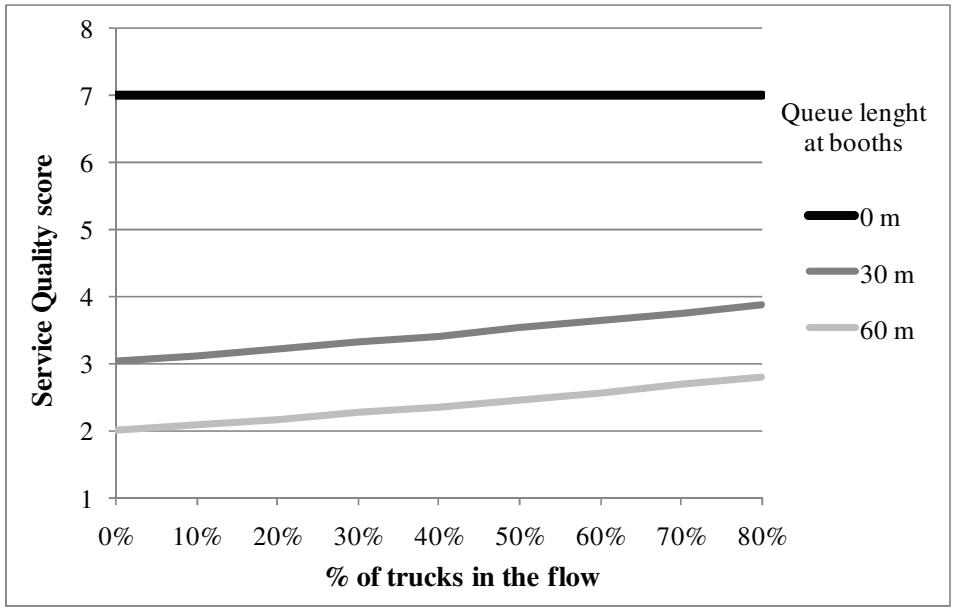

Figure 3: Sensitivity graph of quality of service to the percentage of trucks and queue length factors

Figure 4 presents the variation of the service quality score as a result of variations in the mean queue lengths at the booths as perceived by the different groups for flows composed of 30% of trucks.

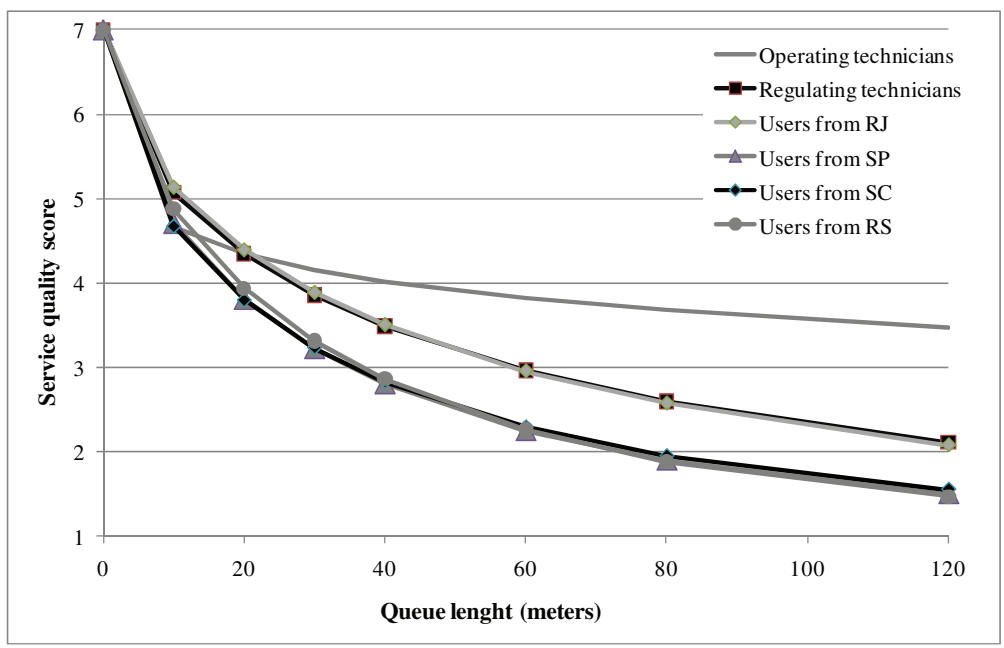

Figure 4: Effect of queue length at the booths on the score of quality of service, as perceived by the different groups for flow composed of 30% of trucks

Table 2 presents the queue length limits associated to levels of service according to the model obtained for each group, assuming a percentage of 30% of trucks in the flow.

The scale adopted in this method does not present any relation between the levels of service and the plaza capacity. This dissociation between levels of service and capacity is justified insofar as the traffic situations represented by the scenarios tested in the qualitative research are not related to plaza capacity. Thus, in order to avoid inadequate comparisons with the traditional HCM levels of service scale that relates the level E to road capacity, the scale proposed is associated with the concepts used to evaluate the scenarios in qualitative research.

Table 2. Scale of levels of service for flows comprising 30% trucks, according to the perceptions of the different groups

Level of Service	Queue lenght (L meters)					
	Users from RS	Users from SC	Users from SP	Users from RJ	Regulating technicians	Operating technicians
Very good to Excellent	$L \leq 3$	$L \leq 2$	$L \leq 2$	$L \leq 3$	$L \leq 3$	$L = 0$
Good to Very good	$3 < L \leq 9$	$2 < L \leq 7$	$2 < L \leq 8$	$3 < L \leq 11$	$3 < L \leq 11$	$0 < L \leq 4$
Fair to Good	$9 < L \leq 19$	$7 < L \leq 17$	$8 < L \leq 17$	$11 < L \leq 27$	$11 < L \leq 27$	$4 < L \leq 42$
Bad to Fair	$19 < L \leq 37$	$17 < L \leq 35$	$17 < L \leq 35$	$27 < L \leq 58$	$27 < L \leq 58$	$42 < L \leq 295$
Very bad to Bad	$37 < L \leq 73$	$35 < L \leq 76$	$35 < L \leq 73$	$58 < L \leq 129$	$58 < L \leq 134$	--
Extremely bad to Very bad	$L > 73$	$L > 76$	$L > 73$	$L > 129$	$L > 134$	--

The scale of the operating technical staff perception does not present queue length values for “Very bad to Bad” and “Extremely bad to Very bad’, since the values corresponding to these levels of service are too high, given the greater tolerance of this group concerning queues at the booths.

The scales of level of service derived from the perception of users from Santa Catarina, São Paulo and Rio Grande do Sul are very similar (Table 2). The scales referring to the perception of toll plazas users from Rio de Janeiro and the perception of technical staff from regulating agencies shows greater tolerance for the length of the queues at the booths, while the scale derived from the perception of technical staff from operating companies is even more tolerant as regards queues at the booths.

Interesting considerations arise from these findings. The majority of toll plazas in the states of Santa Catarina, Rio Grande do Sul and São Paulo are located in interurban roads. According to a national research undertaken by National Confederation of Transport (CNT, 2009), that evaluated the conditions of Brazilian roads, the road network in the state of São Paulo presents higher quality than any other state. We might expect that São Paulo users could have more demanding perception than other states users. However the models indicated that these users, accustomed to interurban roads with better pavement and infrastructure, had quality requirements for toll plazas very similar to the requirements presented by road users from other states.

On the other hand, it should be pointed out that most respondents from the state of Rio de Janeiro often encounter heavier traffic at toll plazas than users of other states. Many of these surveyed users use toll plazas in their daily trips to work, such as the toll at the Rio-Niteroi Bridge, which has long daily queues. The users’ greater tolerance for queues may probably be associated with an adaptation to a daily experience of heavy traffic jams.

The results from this research suggest that it may not be feasible to define a unique scale for level of service valid for all toll plazas in the country. Users’ perceptions about acceptable quality of service are influenced by their experience. The analysis of the typical environments experienced by the respondents suggests that operational conditions play a more important role in their perception about quality of service at toll plazas than overall road infrastructure characteristics.

9. Final considerations

This paper presented a method for the analysis of levels of service at toll plazas, based on the users’ perception of quality of service at plazas. The users’ perception was obtained through qualitative research applied via internet, using videos of simulated toll plazas scenarios. The method was conceived to represent typical characteristics of toll plazas throughout Brazil. The definition of parameters of the simulated scenarios was based on research about flow

conditions and layouts of Brazilian toll plazas. Data collection via internet proved efficient and reliable. The results were consistent and the technique allows interviewing a considerably broader population.

The results of the research were used to estimate models relating level of service at the plazas to (i) the mean queue lengths at the booths (measured in meters); (ii) the percentage of trucks in the flow; and (iii) the number of booths at the plaza. The modeling was performed by regression, resulting in a negative exponential equation, with excellent compliance with the data collected.

The results of the research and the analyses of model sensitivity indicate that "Mean Queue Length at the booths" is the variable that exerts the greatest influence on the quality perceived at the plazas. The increased queue lengths at the booths cause a significant reduction in the quality perceived by users. This was an expected result, since queue length at the booths is directly proportional to the waiting time of users in the queue. The presence of queues at the booths increases user´s feelings of discomfort and inconvenience when crossing the toll plaza. The "Percentage of Trucks" had a small but significant influence on the perception of quality of service. The increase in the percentage of trucks leads to an improvement in the quality perceived by users. This models' behavior can be explained by the fact that, for a similar queue length, the presence of trucks implies in a smaller number of paying vehicles, and a shorter waiting time in queue. The effect of the variable "number of booths" did not prove statistically significant, and this variable was not included in the models.

The method proposes a scale of levels of service related to the quality perceived by users at toll plazas. In order to avoid a possible association with methodologies presented in HCM for analysis of levels of service on highways, which relate level of service "E" to capacity, the proposed scale is structured on concepts of quality, that range from "Excellent" to "Extremely bad", according to a scale used in qualitative research.

A major quality of the method is the use of easily monitored indicators. The indicator "Queue Length" is easily understood by users and operators. It is easy to collect by observation or with the help of video cameras. The percentage of trucks in the flow is also easily obtained by recorded data from the plaza charging system. The adoption of indicators that require simple, practical and robust collection processes is an important factor for the reliability and broad use of this method.

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References

Al-Deek, H. M., & Radwan, A. E. (1995). A framework for evaluation level of service at electronic toll collection plazas. *Proceedings of Transportation Congress: Civil Engineers – Key to World Infrastructure, ASCE, 2*, 1412-1422.

Burris, M. W., & Hildebrand, E. D. (1996). Using Microsimulation to Quantify the Impact of Electronic Toll Collection. *ITE Journal*, *66 (7)*, 21–24.

Choocharukul, K., Sinha, K. & Mannering. F., (2004). User Perceptions and Engineering Definitions of Highway Level of Service: An Exploratory Statistical Comparison. *Transportation Research A*, (38) 677–689.

CNT – Confederação Nacional do Transporte (2009). *Pesquisa Rodoviária 2009: relatório gerencial*. Brasília.

Gulewicz, V., & Danko, J. (1995). Simulation-Based Approach to Evaluation Optimal Lane Staffing Requirements for Toll Plazas. *Transportation Research Record, 1484*, 33-39.

Hostovsky, C., Wakefield, S & Hall, F. L. (2004) Freeway Users' Perceptions of Quality of Service: Comparison of Three Groups. *Transportation Research Record*. 1883, 150-157.

Klodzinski, J., & Al-Deek, H. M. (2002). New Methodology for Defining Level of Service at Toll Plazas. *Journal of Transportation Engineering, 28 (2)*, 173-181.

Lin, F., & Su, C. (1994). Level of Service Analysis of Toll Plazas on Freeway Main Lines. *Journal of Transportation Engineering, 120 (2)*, 246-263.

Pécheux, K. K., Flannery, A., Wochinger, A.., Rephlo, J. & Lappin, L. (2004). Automobile Drivers' Perceptions of Service Quality on Urban Streets. *Transportation Research Record,* 1883, 167-175.

Pécheux, K. K., Pietrucha, M. T. & Jovanis, P. P. (2000) User Perception of Level of Service at Signalized Intersections: Methodological Issues. *Transportation Research Circular E-C018: Proceedings of the Fourth International Symposium on Highway Capacity,* TRB, 322–335.

Polus, A. (1996). Methodology and Simulation for Toll Plaza Analysis. *Road & Transport Research, 5 (1)*, 44-68.

PTV (2006) VISSIM v.4.30 User Manual. *PTV – Planung Transport Verkehr AG.*

StatPoint (2005) The User's Guide to STATGRAPHICS Centurion XV. Virginia, EUA: *Statpoint, Inc.*

TRB (2000) Highway Capacity Manual. *Special Report n. 209*. Transportation Research Board, National Research Council, Washington, D. C., EUA.

Van Dijk, N. M., Hermans, M. D., Teunisse, M. J. G. & Shuurman, H. (1999) Designing the Westerscheldetunnel Toll Plaza Using a Combination of Queueing and Simulation. *In:* Farrington, P. A., Nembhard, H. B., Sturrock, D. T.,& Evans, G. W. (*eds.) Proceedings of the 1999 Winter Simulation Conference,* Netherlands. 1262-1279.

Wanisubut, S. (1989) A Toll Plaza Simulation Model and Level-of-Service Criteria. *Ph.D. Thesis*, Polytechnic University, University Microfilms International, Ann Arbor, Michigan, USA.

Washburn, S. S., & Kirschner, D. S. (2006). Rural Freeway Level of Service Based on Traveler Perception. *Transportation Research Record,* 1988, 31-37.

Woo, T. H., & Hoel, L. H. (1991). Toll Plaza Capacity and Level of Service. *Transportation Research Record, 1320*, 119-127.

Zarrillo, M. L. (1998) Development and Applications of TPMODEL: A Queuing model describing Traffic Operations during Electronic Toll Collection (ETC). *Ph.D. Thesis*. University of Central Florida - UFC, Florida, USA.