An analytical hierarchy process-based assessment of factors affecting service performance of tollbooth operators

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The efficiency of manual toll transactions is highly dependent upon the service performance of tollbooth operators. The latter is a multi-attribute decision making (MADM) problem, as the performance of the tollbooth operators is influenced by various criteria such as traffic operation, tollbooth ergonomics, etc. The present study has used the analytical hierarchy process (AHP), a MADM method, to evaluate the criteria affecting the service performance of tollbooth operators. The identified criteria are further ranked based on their significance so that the concessionaire as a decision-maker may identify the most important criteria and take appropriate decisions to improve the service performance of tollbooth operators. Based on the available literature, the criteria affecting the service performance of tollbooth operators included service time, their capability in terms of service training, shift timings and personal safety. A structured AHP questionnaire was prepared for developing the relative importance matrix from the perception of the tollbooth operator. The weights were obtained from the AHP relative importance matrix and used for setting the priorities. The results show that the operator's capability as a criterion and training given to tollbooth operators as a sub-criterion have the highest priorities with weights of 0.51 and 0.214 respectively (global weight). Finally, sensitivity analysis was performed to check the effect of change in weights of criteria on the service performance of tollbooth operators. Thus, the output could be used by the concessionaire to meet the requirements of the tollbooth operators for enhancing their service performance in order to improve the service level of toll plazas.

Keywords: Analytical hierarchy process, multi-attribute decision-making, service performance, tollbooth operators, weights.

IN India, many road projects are being undertaken on a public–private partnership (PPP) basis to enhance the existing road capacity for higher efficiency and safety. The private stakeholders initially invest in the project and recover the investment and benefits via toll charges from the road users during the operations stage. Since January 2020, the electronic toll collection (ETC) system (locally FASTag system) has been made mandatory for toll payment on the national highways (NHs), thus replacing the traditional manual toll collection (MTC) system. In India, about 543 toll plazas are operational on NHs, and more than 200 toll plazas on the state highways (SHs).

Traffic in India exhibits poor lane discipline and is highly heterogeneous, with more than seven vehicle classes. On NHs, vehicle classes like small cars (SCs), big cars (BCs), light commercial vehicles (LCVs), buses, heavy commercial vehicles (HCVs), multi-axle vehicles (MAVs) and trailers are dominant and need to pay toll[1,2]. Motorized two-wheelers (M2Ws) and motorized three-wheelers (M3Ws) are also present on NHs, but toll is not collected from them until an alternative road is present in the form of a service road for the same stretch[3]. This heterogeneity causes variability in traffic behaviour[4]. It is observed on the field that in a particular dedicated lane (specific vehicle-class lane), different vehicle classes form a queue due to the driver behaviour of joining the shortest queue to incur the least probable delay (Figure 1). This causes mixed traffic conditions at toll plazas, and the same is observed more or less at all the toll plazas across India[5].

The toll payment on SHs is still done manually[6]. In the MTC lane, the tollbooth operator plays an important role as the transaction of toll rate is carried out by the driver and tollbooth operator interface[5,7]. The MTC system still

Figure 1. Mixed traffic conditions observed in the field.

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Table 1. Toll collection methods

Source (ref. no.)	Country	Toll collection system
8	Germany	Manual, automatic payment system, payment via the internet
55	Italy	Manual, credit card, automatic
9	United Kingdom	Manual, credit card and fuel card, automated payment system, congestion charging, and ultra low emission zone
56	Spain	Manual, credit card and shell card
57	Sri Lanka	Manual, automatic number plate recognition (ANPR), electronic toll collection (ETC), multi-lane free flow (MLFF)
58	Thailand	Manual, ETC
59, 60	China	Manual, semi-automatic manual collection, ETC and weight-based collection
61, 62	USA	Manual, ETC, high occupancy toll lanes (HOV), high occupancy toll lanes (HOT), congestion pricing
63	India	Manual, ETC

exists in many countries due to operational or policy reasons. Table 1 shows the wide range of the technologies used for toll collection, from MTC to the latest congestion pricing. MTC is not only used in developing countries like India, Sri Lanka, etc., but also in developed countries having the latest infrastructure and technology like USA, UK and Germany[8,9]. Further, in many developed countries, the visitors do not have transponders installed, and so the authorities prefer to use the MTC system in such cases. The MTC system, however, causes significant delay to users in comparison to the ETC system (Table 1)[10].

Congestion at toll plazas mainly depends upon the service rate at tollbooths. The queue starts to develop when the service rate is lower than the arrival rate, which causes bottleneck formation on the highways resulting in delay to the road users[11]. The performance of the tollbooth operator and that of the tollbooth are not the same. The service performance of the tollbooth operator is a key characteristic affecting the operations in the MTC lanes and not in the FASTag lanes. The tollbooth operator in the FASTag lane is present only to scan the FASTag manually in case of any technical error.

The tollbooth performance in MTC lanes is the combined effect of the tollbooth operator's behaviour, driver's behaviour and the vehicular characteristics[5,7]. The tollbooth performance is measured in terms of service rate that depends on service time. The service time is the time required for toll transaction[12]. Less the service time, more will be the service rate, and vice versa. Therefore, the evaluation of staff (tollbooth operator's) service performance is an essential criterion for optimizing the service rate at the toll plazas. The performance of tollbooth operators depends on their skills and motivation (a qualitative measure of willingness to perform)[13]. It represents people's accomplishments and the efforts that led to such achievements[14]. Performance evaluation is a process oriented towards quantitative and qualitative measures of an employee's current performance, through which managers ensure that their activities and outputs fulfill the organizational goals[15]. Thus, the performance management system should consider employee behaviour and attitude that help the organization's growth align with the goals.

The performance evaluation of workers is a complex task which comprises various aspects and evaluation criteria[16]. The managers at any firm are continuously taking decisions for the effectiveness and growth of their organization. An organization consists of shareholders, workers and customers with the workers, playing an important role. As discussed above, the performance management system of workers consider worker behaviour and attitude that depend on a number of criteria like the working environment, quality of work, timing of work, etc. Also, previous studies have assessed the performance evaluation of workers as a multi-attribute decision-making (MADM) problem[15–19]. The present study also chooses the same approach.

This study has identified the criteria that affect service performance of tollbooth operators. The criteria are endogenous and exogenous in nature, including safety, comfort, physical and mental health, etc. The tollbooth operators were asked about these criteria and how they affect their service performance. Based on their responses, a database was generated.

This database has been analysed to prioritize the criteria affecting the service performance of tollbooth operator to provide a ranking. Based upon the ranking, the concessionaire may decide on improving the service performance of the tollbooth operator and, therefore, the concessionaire is considered the decision-maker (DM).

Literature review

AHP method

The performance of a worker depends upon various criteria, and hence it falls under MADM. Various methods have been used to solve MADM problems, such as the weighted sum method (WSM), weighted product method (WPM), analytic hierarchy process (AHP), revised AHP and the technique for order preference by similarity to ideal solution (TOPSIS)[20]. Table 2 shows a comparison of different MADM methods describing the concept, methodology and their applications. The MADM methods are used for

Table 2. Comparison of different multi-attribute decision making (MADM) methods

Method	Problem reference	Degree of compensation	Type of information	Information features	Dependencies between criteria	Type of method	Theory	Application	Reference
Analytic hierarchy process (AHP)	R	P	Qual, Quan	Cr, Fz	H	S	Hierarchical	Performance analysis, planning and political strategy, transportation problems	25, 34
Analytical network process (ANP)	R	P	Qual, Quan	Cr, Fz	H, I	S	Hierarchical	Transportation, geomatics, energy-related problems	64, 65
Simple multi attribute rating technique (SMART)	R	P	Qual, Quan	Cr	I	S	MAUT	Construction, environmental, transportation and military problems	66, 68
Technique for order of preference by similarity to ideal solution (TOPSIS)	R	F	Quan	Cr	I	O	MAUT	Supply-chain management, bridge resilience study, business and finance, human resource, environmental	69, 70
Elimination EtChoix Traduisant la REalité (ELECTRE)	C	P	Qual, Quan	Cr	I	S, O	Out-ranking method	Environmental, economics, transportation and water management-related problems	71
Preference ranking organization method for enrichment evaluation (PROMETHEE)	R	P	Quan	Cr, Fz	H	O	Out-ranking method	Supply chain management, manufacturing problems, business and finance, human resource, environmental	72
Data envelopment analysis (DEA)	R	F	Quan	Cr, Fz	NA	O	Post ante analysis, linear programming technique	Utilities, road safety, agriculture, business problem, etc.	73–75
Simple additive weight (SAW)	R	F	Quan	Cr	NA	O	Weighted linear combination method	Financial management, Formation of resilience index, water management, etc.	76, 77

C, Choice; R, Ranking; P, Partial; F, Full; Qual, Qualitative; Quan, Quantitative; Cr, Crisp; Fz, Fuzzy; I, Interdependent; H, Hierarchical; S, Subjective and O, Objective.

different research problems, such as for choice (denoted as C in Table 2) or ranking (denoted as R). The DM can choose a criterion/subset from the given sets for a single alternative. In comparison, the DM can arrange the alternatives in sequential ranking preference. Table 2 also shows the degree of compensation. The compensatory algorithms combine multiple criteria to find the best alternative[21]. The degree of compensation can be partial (P), full (F), or non-compensatory[22]. Data types, such as crisp (Cr, deterministic) and fuzzy (Fz, non-deterministic) can be used in the MADM methods. The methods given in the literature are both subjective and objective[23]. The subjective

Table 3. Different applications of the AHP method

Reference	Applications	Methods used
78	Highway planning	AHP and multi-attribute value (MAV)
31	Service areas on expressways	Fuzzy AHP
33	Determination of bridge health indices	AHP
79	Track selection of light rail transit (LRT)	AHP
80	Pedestrian zone study	AHP
70	Evaluation of congestion levels at intersections	AHP-TOPSIS
81	Evaluation index with safety, economic, technical, and time criteria for highway projects	AHP and grey correlational matrix
28	Sustainability criteria of transportation systems in urban areas	AHP
29	Selection of parking lots	Fuzzy AHP-TOPSIS
82	Plant location selection	Delphi-AHPPROMETHEE
40	Bridge resilience index	AHP-TOPSIS
50	Green building rating	Fuzzy-AHP

methods consist of determining the weights of the criteria based on subjective weights given by the DMs through personal communication. On the other hand, the weights are derived based on observations in the objective method. Among all the methods, AHP has been widely used for decision making since 1980 (refs 24, 25) for mechanical and chemical engineering problems[26], staff behavioural studies, construction and transportation engineering problems[27–30]. As observed, AHP is a subjective method.

Saaty[25] introduced the AHP method in 1987 to determine the weights of the criteria. AHP is a hierarchy system of objectives/goals, criteria and, finally, alternatives. It is used to decide how the DMs think using the weights obtained from the pairwise comparative matrix. The method is applicable for both discrete and continuous data, and can deal with the qualitative and quantitative criteria of decision-making[31]. It is easy to understand and can be applied to decision-making problems[32]. Table 3 shows the different applications of the AHP method and its hybrid form in different transportation studies. AHP is utilized in the present study because it can handle the consistencies and inconsistencies in the responses with the help of an appropriate analytical approach for determining the consistency index[24,25,33]. Further, when there are constraints regarding the physical or statistical measures, AHP supports developing measures in physical or social environments and is also used to convert the subjective assessments into relative weights[34].

Toll plazas

Various studies were carried out on the performance of the tollbooth operators and service time was one of the criteria affecting it[35]. Table 4 illustrates the key findings of the research carried out all over the globe for service time and delay. It is observed that service time is affected by a multitude of parameters such as vehicle class, traffic composition, toll rate, approaching traffic volume and human behaviour. Further, the average service time was reduced by 77% due to implementation of the FASTag system in India[10].

Sehgal *et al.*[36] showed that working efficiency and average life of the tollbooth operators were affected by concentration of particulate matter ($PM_{2.5}$), decreasing their service performance. According to Sharma[37], the highest 8 h average concentration of $PM_{2.5}$ was observed at municipal (urban) toll plazas (219 $\mu g/m^3$), followed by highway toll plazas (150 $\mu g/m^3$). The tollbooth operators were mainly affected by vehicular emissions, as the vehicles are in idling mode in the tollbooth during toll transaction[38,39].

Objective of the present study

The literature review shows that the throughput in the MTC lane mostly depends on the service performance of the tollbooth operators. The safety and capability of tollbooth operators also affect his/her service performance[40–42]. The service performance evaluation of tollbooth operators has been reported in the literature, but the critical criteria affecting the performance have not been reported in previous studies. Hence, the prime objective of the present study is to evaluate different criteria affecting the service performance of tollbooth operators and recommend priorities to improve their overall service performance. For this, the AHP method is used for decision-making. The effect of operational traffic parameter (service time) on the service performance of tollbooth operators is evaluated. The impact of weight of the personal factors such as the capability/potential of tollbooth operators to carry out work effectively is also studied. Lastly, the safety of their lives is considered one of the main criteria, as a safe environment affects the mentality of the tollbooth operators.

Methodology and data collection

In order to meet the study objectives, a questionnaire was framed that included the exogenous and endogenous criteria (Figure 2). It was used to interview the tollbooth operators and record their responses. A database was generated for further analysis. The data for the present study were collected at five different toll plazas located on various

Table 4. Key findings of studies carried out on service time and delay at toll plazas

Reference	Study area	Focus of the study	Key findings
41	New York, USA	Delay at manual toll plazas	Service time and queue length were the prominent factors responsible for the delay.
			Service time was found dependent on traffic volume, traffic composition, number of tollbooths and the behaviour of tollbooth operators.
42	Taiwan	Level of service (LOS) analysis of manual toll plazas	Performance of the tollgate could be significantly affected by service capacity, vehicle arrival pattern, number of available gates and behaviour of the drivers.
			Average queue length and average delay were taken for delineation of LOS.
			Service time varied between 2 and 30 sec, considering all vehicle classes.
83	Florida, USA	LOS at toll plazas	Service time for manual toll collection (MTC) vehicles was 6 sec and for ETC vehicles it was about 4 sec.
			Queue delay was taken as a parameter for determining LOS, at it represents the level of inconvenience experienced by the drivers'.
84	Canada	Analysing delay and environmental impacts of toll plazas using simulations	After 35% penetration of the ETC-equipped vehicles, the benefits of using ETC lanes decreased as delay in ETC lanes started increasing due to maximum throughput.
35	Brazil	Evaluation of tollbooth workers' performance	Toll plaza operations was greatly affected by service time.
			Service time was highly affected by traffic volume at the toll plazas.
			Service time per vehicle was affected by the number of bills and coins that must be processed by the tollbooth collector or automated coin machine.
7, 43	India	Analysis of service time of manually operated toll plazas	Traffic composition, vehicle class, leader–follower pair, human behaviour (drivers and tollbooth operators), location and toll rate were the most important criteria for service time.
			The service time considering all vehicle classes varied between 2.36 and 50.96 sec, with an average value of 14.60 sec. These variations in service time were due to mixed traffic conditions observed in the field.
85	India	Effect of FASTag penetration on queue delay	Simulation results showed that with full implementation of FASTag in India, the queue delay decreased on an average by 95%.
10	India	Effect of FASTag system in India	The service time of FASTag lanes varied between 0.12 and 13.12 sec.
			A decrease of 77% in average service time was observed due to implementation of FASTag in India.

Rating Scale

Definition	Level of importance
Equal importance	1
Moderate importance	3
Strong importance	5
Very Strong importance	7
Extreme importance	9
Intermediate values between two adjacent judgment	2,4,6,8

Factors important according to you

Please tick (✓) which resilience property/factor is more important				Please indicate the level of importance								
Service Time		Capability		1	2	3	4	5	6	7	8	9
		Safety		1	2	3	4	5	6	7	8	9

Please tick (✓) which resilience property/factor is more important				Please indicate the level of importance								
Capability		Safety		1	2	3	4	5	6	7	8	9

Figure 2. Snapshot of the analytical hierarchy process (AHP) questionnaire.

NHs in the western part of India. The Ghoti Toll Plaza (GTP), Pimpalgaon Baswant Toll Plaza (PBTP) and Chandwad Toll Plaza (CTP) are located on NH-3, connecting Agra to Mumbai, whereas Bokarwadi Toll Plaza (BTP) is located on NH-52. The Kambrej Toll Plaza (KTP) is located on NH-48, connecting New Delhi to Mumbai. All

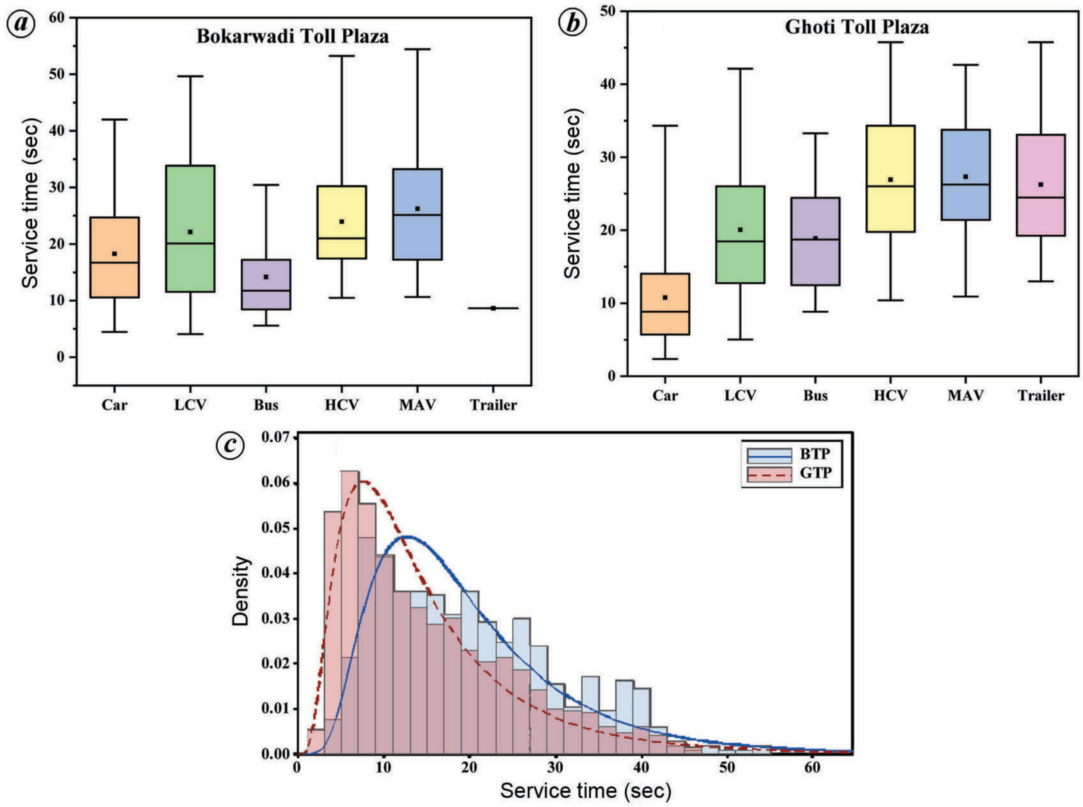

Figure 3. Variation of service time. ***a***, ***b***, Box Plots showing vehicle class wise variation at (***a***) Bokarwadi Toll Plaza (BTP) and (***b***) GTP. (***c***) Probability density plot for the combined data at BTP and GTP.

these toll plazas are located on major through fares with varying traffic volumes. As a result, tollbooth operators' instructions to users and the environment will be reflected in their responses. In addition, the reactions of tollbooths operators will reflect the variance in their behaviour.

A total of 150 respondents were interviewed to generate a database for further analysis. The endogenous and exogenous criteria were explained in simple language to the tollbooth operators to get the responses for the questionnaire. The responses received were further used to prepare a relative importance matrix to set the priorities for improving the service performance of the tollbooth operators. Figure 2 also shows the pairwise comparison scale used in AHP. A rating of '1' would indicate 'equal importance' of the items constituting the pair, and a rating of '9' would indicate 'extreme or absolute importance' of an item 'i' in the row of the pairwise comparison matrix over another item 'j' in the column of the matrix. Correspondingly, the rating of 'j,' relative to 'i', would be 1/9.

To examine whether an inverse relationship exists between the capability of tollbooth operators and the service time, we have extracted service time data from video data collected at the concerned toll plazas in earlier studies[5,10]. The camera was kept 10–20 m away from the tollbooth on the island at the downstream side for capturing service time of the vehicles.

From the collected field data, the vehicle class-wise service time data were extracted using AVIDEMUX software in the traffic engineering laboratory of the institute. Six vehicle classes were considered, including cars, LCVs, buses, HCVs, MAVs and trailers, depending on the toll rate and referring to the literature[5]. Figure 3 *a* and *b* shows the vehicle class-wise service time distribution at BTP and Ghoti Toll Plaza (GTP) respectively. Total samples observed at BTP and GTP were 585 and 1475 respectively. The service time is minimum for cars and maximum for MAVs at BTP, while it was maximum for trailers at GTP (the data samples for buses and trailers were less at BTP).

For the same vehicle class, for example, consider cars, the service time at BTP varied between 4.48 and 42.00 sec, while at GTP, it ranged from 2.36 to 34.32 sec. These variations in the service time range capture the effect of traffic composition, toll rate as well as drivers' and tollbooth operators' behaviour. This is well explored in the literature[7,42,43]. Figure 3 *c* shows the probability density function plot for the combined data at both locations. It shows that the service time is left-skewed and thus follows a lognormal distribution. It can be seen from the box plots that the mean is always higher than the median, depicting skewed distribution. This shows that the service time varies among the vehicle classes and also with location.

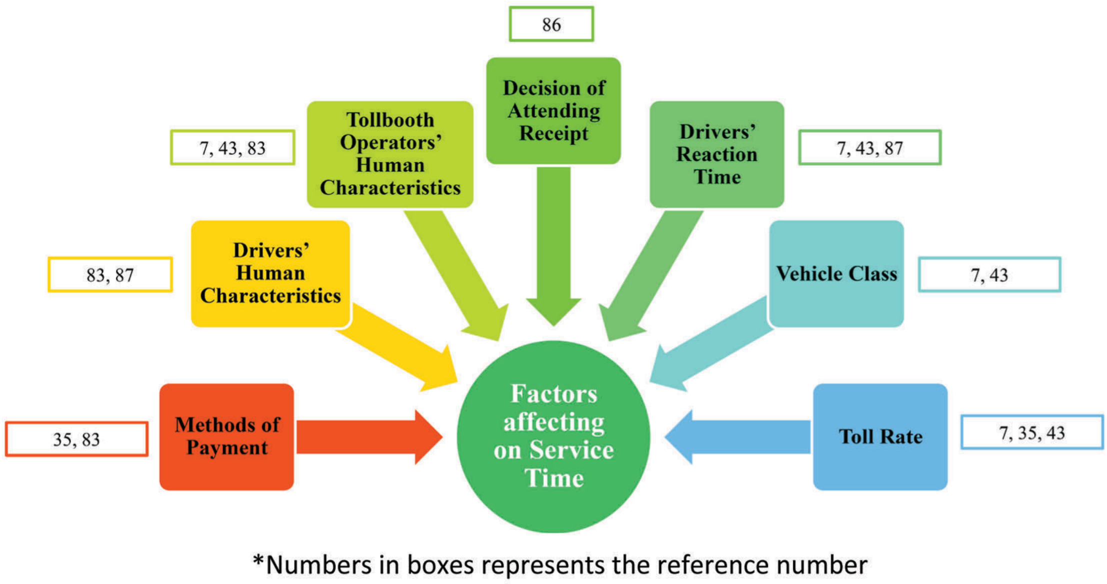

Figure 4. Factors affecting service time.

In addition to these variations of vehicle class-wise and location-wise service time, simultaneous equations have been developed for the prediction of service time of different vehicle classes in one of our earlier studies[44]. Observing the wide variations in service time for the same as well as other vehicle classes, we can infer that service time is determined by a variety of factors, including vehicle type, vehicle percentage, vehicle arrival pattern, and the behaviour of drivers and tollbooth operators. We have related service time with the traffic composition and approach volume as parameters to estimate the vehicle class-wise service time as described in Navandar *et al.*[44].

Thus, from all the analyses, it is evident that the service time is not constant for a specific vehicle class, but varies with traffic composition, approach volume, and the behaviour of drivers and tollbooth operators. Hence, capability of the tollbooth operators and service time do not have an inverse relationship because service time is determined not only by the capability of the tollbooth operators, but also by the other criteria listed above. This can be verified from the literature (Figure 4). In the present study, we have considered the capability of the tollbooth operators and service time as different subsets at level 1 for defining the service performance of the tollbooth operators.

Along with service time and capability of the tollbooth operators, their safety is also considered in the present study as a primary criterion (level 1, considered as a subset) for the evaluation of the service performance of the tollbooth operators[5,7,36,45] (superset). The above-mentioned three main criteria consist of both exogenous and endogenous criteria. Exogenous criteria have external causes and come from external systems, including safety, comfort, convenience, etc.[46,47]. On the other hand, endogenous criteria have internal causes and origin, such as physical and mental health, gender, etc.[48]. For service time, the sub-criteria (level 2) consist of the criteria affecting service time such as type of vehicle, type of lane (whether mixed or dedicated), driver's seat height, toll rate, queue length, leader–follower pair, vehicle arrival and requirement of an extra attendant (Figure 4)[7].

Further, the tollbooth operator's capability depends on the training received, shift timings, refreshment, number of breaks, health condition and ergonomics of the booth and plaza[35]. Safety also depends upon the size of the cabin, emergency exits, safety uniform provided and pure oxygen supply[35,49]. All these criteria were analysed in the present study using AHP below.

The present study uses AHP, which involves pairwise comparison of criteria (level 1) and sub-criteria (level 2) across a hierarchy representing a decision-making process[20,25,40]. The criteria (level 1) in the present study, i.e. service time, safety and capability of tollbooth operators, which affect their service performance, are considered solely based on the literature review and field experience. As discussed above, the service time related sub-criteria mostly occur due to the random arrival of vehicles.

The other sub-criteria (level 2) related to the tollbooth operator's safety and capability are related to the design aspects of the tollbooth and managerial decisions. Hence, whatever the effect of each sub-criterion, it will affect the service performance of the tollbooth operators as a whole. From the extensive literature no interactions between the criteria and sub-criteria were found. Hence, in the present study, no relation was considered between the criteria and sub-criteria.

The goal (superset), criteria (level 1 referred to as a subset), and sub-criteria (level 2) were decided (Figure 5).

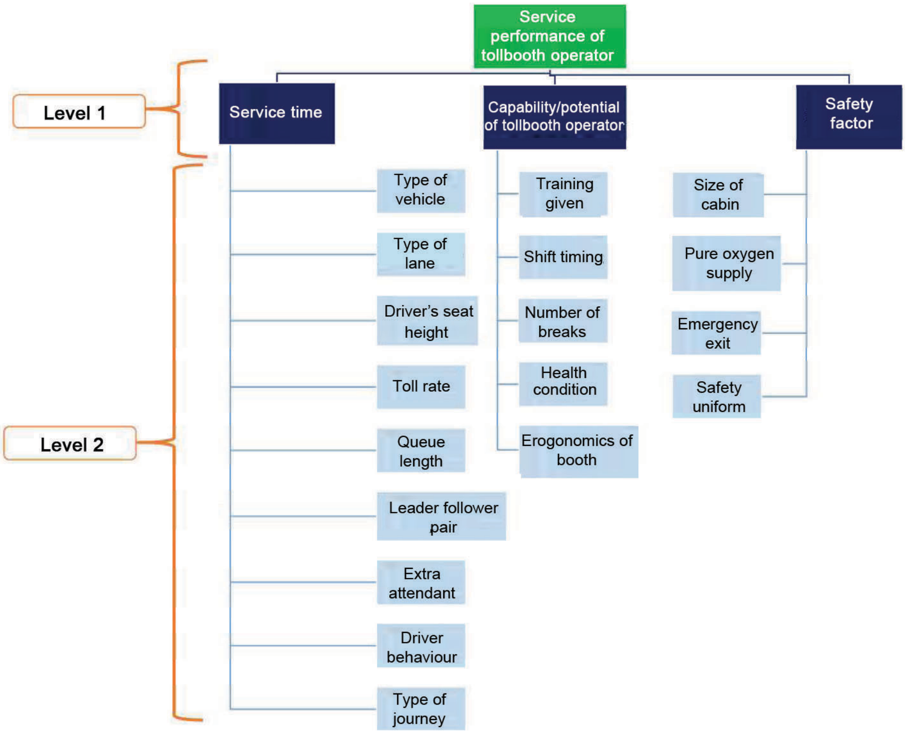

Figure 5. Hierarchy considered for the AHP questionnaire.

Then the relative importance matrix was found by interviewing the respondents (here, tollbooth operators) having work experience in the field.

$$A_{M\times M} = \begin{array}{c} \\ E_1 \\ E_2 \\ E_3 \\ \vdots \\ E_M \end{array}\begin{array}{c} \begin{array}{ccccc} E_1 & E_2 & E_3 & \dots & E_M \end{array} \\ \begin{bmatrix} 1 & e_{12} & e_{13} & \dots & e_{1M} \\ e & 1 & e_{23} & \dots & e_{2M} \\ e_{31} & e_{32} & 1 & \dots & \vdots \\ \vdots & \vdots & \dots & \ddots & \vdots \\ e_{M_1} & e_{M_2} & e_{M_3} & \dots & 1 \end{bmatrix} \end{array}, \quad (1)$$

where $A_{M\times M}$ is the relative importance matrix (say A_1), M the number of criteria and e_{ij} denotes the comparative importance of criterion i with respect to criterion j. In the matrix, $e_{ij} = 1$ when $i = j$ and $e_{ji} = 1/e_{ij}$.

The relative normalized weight (w_j) of each criterion was determined by taking the geometric mean (GM) as shown in eq. (2).

$$\mathrm{GM}_j = \left[\prod_{j=1}^{M} e_{ij}\right]^{1/M}, \quad (2)$$

$$w_j = \frac{GM_j}{\sum_{j=1}^{M} GM_j}. \quad (3)$$

The matrix in eq. (1) was taken as A_1 and the weighted matrix as A_2. Matrices A_3 and A_4 were obtained as shown in eqs (4) and (5).

$$A_3 = A_1 * A_2, \quad (4)$$

$$A_4 = \frac{A_3}{A_2}, \quad (5)$$

where $A_2 = [W_1, W_2 \dots W_j]^T$.

Then, maximum eigenvalue ($\lambda_{\max}$) was calculated by taking the average of matrix A_4.

The consistency index (CI) was determined from eq. (6).

$$\mathrm{CI} = \frac{\lambda_{\max} - M}{M - 1}. \quad (6)$$

The consistency ratio (CR) was calculated using eq. (7), with a maximum value of 0.1. Random index (RI) was taken from previous studies[24,25].

$$\mathrm{CR} = \frac{\mathrm{CI}}{\mathrm{RI}}. \quad (7)$$

If CR > 0.1, then the combined matrix has to be developed. The procedure for finding the combined matrix as suggested in earlier studies[35,50] has been adopted in the present study. Suppose the values given by the respondents

Table 5. Relative importance matrix of the three main criteria for respondent 1

Matrix	A_1 Service time	Capability	Safety	Geometric mean	Weights A_2	A_3	A_4	Rank
Service time	1	1/9	3	0.69	0.13	0.42	3.17	3
Capability	9	1	8	4.17	0.80	2.54	3.17	1
Safety	1/3	1/8	1	0.35	0.07	0.21	3.17	2

Table 6. Relative importance matrix for sub-criteria in criterion 1 (service time) for respondent 1

Matrix	A_1 Type of vehicle	Type of lane	Seat height	Toll rate	Queue length	Leader–follower pair	Driver behaviour	Type of journey	Extra attendant	Geometric mean	Weights A_2	A_3	A_4	Rank
Type of vehicle	1	1/9	1/7	1/8	1/9	1/5	1/3	1	1/2	0.27	0.02	0.20	9.23	9
Type of lane	9	1	2	2	1	4	6	9	4	3.16	0.25	2.31	9.32	1
Seat height	7	1/2	1	1/3	1/2	2	3	7	3	1.61	0.13	1.21	9.53	4
Toll rate	8	1/2	3	1	1/5	5	3	5	3	2.01	0.16	1.66	10.48	3
Queue length	9	1	2	5	1	6	4	3	5	3.17	0.25	2.66	10.68	1
Leader–follower pair	5	1/4	1/2	1/5	1/6	1	2	5	1	0.84	0.07	0.67	10.22	5
Driver behaviour	3	1/6	1/3	1/3	1/4	1/2	1	7	5	0.85	0.07	0.73	10.92	5
Type of journey (single, double, local pass)	1	1/9	1/7	1/5	1/3	1/5	1/7	1	2	0.34	0.03	0.17	6.50	7
Extra attendant	2	1/4	1/3	1/3	1/5	1	1/5	1/2	1	0.47	0.04	0.38	10.26	8

Table 7. Relative importance matrix for sub-criteria in criterion 2 (capability) for respondent 1

Matrix	A_1 Training given	Shift timing	Number of breaks	Ergonomics of tollbooth	Health condition	Geometric mean weights	Weights A_2	A_3	A_4	Rank
Training given	1	1/5	1/8	1/6	1/7	0.23	0.03	0.18	5.18	5
Shift timing	5	1	1/3	1/2	1/3	0.77	0.12	0.60	5.16	4
Number of breaks	8	3	1	2	3	2.70	0.40	2.19	5.42	1
Ergonomics of tollbooth	6	2	1/2	1	1/3	1.15	0.17	0.90	5.24	3
Health condition	7	3	1/3	3	1	1.84	0.27	1.51	2	5

for a_{12} are $x_1, x_2, \ldots, x_n$ and priority weights (obtained by subtracting CR from 1) are $w_1, w_2, \ldots, w_n$, then for the combined matrix, the value of e_{12} is given by eq. (8).

$$e_{12} = [x_1^{w_1} * x_2^{w_2} * \ldots x_n^{w_n}]^{\frac{1}{(w_1+w_2+\ldots w_n)}}. \tag{8}$$

Similarly, other values were calculated for different e_{ij} cells.

Then the ranking was given according to the weights. Finally, sensitivity analysis was performed.

Results

Based on the responses gathered from the tollbooth operators, the relative importance matrices were examined separately (with the procedure specified in the methodology section). Some of the relative importance matrices were found to be consistent (having CR value less than 0.1), but some were found to be inconsistent. Tables 5–8 show one such sample of relative importance matrix for one respondent (from the perspective of the tollbooth operator). Table 5 shows the matrix-wise analysis for the three main criteria, i.e. service time, capability and safety (denoted as matrix A_1). Matrix A_2 shows the matrix of weights. A_3 and A_4 have been developed using eqs (4) and (5). Considering matrix A_1, the value 1/9 indicates that the capability is extremely important compared to service time. The sum of the geometric mean is 5.21. The weight for service time is calculated as $w_1 = 0.69/5.21 = 0.13$.

Similarly, for the other two criteria, weights were calculated. Then λ_{max} was obtained by taking the average of the A_4 matrix as 3.17. From this value, CI was obtained as 0.08. For CR calculation, the RI value for the three criteria

Table 8. Relative importance matrix for sub-criteria in criterion 3 (safety) for respondent 1

	A_1						Weights			
Matrix	Size of cabin	Pure oxygen provision	Air pollution	Emergency exit	Safety uniform/ environment	Geometric mean	A_2	A_3	A_4	Rank
Size of cabin	1	1/7	9	7	9	2.41	0.35	2.13	6.03	2
Pure oxygen provision	7	1	7	5	7	4.43	0.65	4.39	6.76	1
Air pollution	1/9	1/7	1	2	1	0.50	0.07	0.42	5.78	4
Emergency exit	1/7	1/5	1/2	1	5	0.59	0.09	0.63	7.24	3
Safety uniform/environment	1/9	1/7	1	1/5	1	0.32	0.05	0.27	5.80	5

Table 9. Combined relative importance matrix for the three main criteria

	A_1			Weights	
Matrix	Service time	Capability	Safety	A2	Rank
Service time	1.00	0.15	0.21	0.08	3
Capability	6.48	1.00	1.22	0.51	1
Safety	4.66	0.82	1.00	0.41	2

Note: Consistency check. Consistency ratio (CR) = 0.00 < 0.1 → matrix is consistent.

was taken as 0.52 (ref. 25) and CR obtained as 0.16. This value is more than 0.1, indicating that the weights are inconsistent. The results show that the tollbooth operator's capability has obtained the highest weight (0.80) and thus rank 1, compared to service time and safety. Here, the capability is given a weightage of 0.80, indicating that the service performance of the tollbooth operators will improve significantly if their capability is enhanced. In the present study, capability is characterized by several endogenous and exogenous factors such as training provided, shift timing, health condition, etc. (Figure 5). Then the weights of these sub-criteria are obtained, which shows that the training provided has the highest weightage (0.42, i.e. the capability of the tollbooth operators is enhanced by proper training). These quantifications will help determine the importance of criteria or sub-criteria in terms of local and global weights.

Similar to the above analysis, the CR values in Tables 6, 7 and 8 are 0.059, 0.067 and 0.298 respectively. These are consistent for the sub-criteria of main criteria 1 and 2 (i.e. service time and capability) but inconsistent for criterion 3 (safety). The CR values are for one tollbooth operator's perception and so some weights are inconsistent. To overcome this problem, eq. (8) is used to get consistent results.

Table 9 shows the combined matrix for the three main criteria (i.e. service time, capability and safety) derived using eq. (8). In Table 9, A_1 is the relative importance matrix and A_2 shows the weights. A_3 and A_4 matrices are developed using eqs (4) and (5). Considering matrix A_1, the value 1/6 indicates the capability is essentially important than service time from the tollbooth operator's perspective. The sum of the geometric mean was 3.88. The weight for service time was calculated as $w_1 = 0.32/3.88 = 0.08$. Similarly, for the other two criteria, weights were calculated. Then the $\lambda_{\max}$ was obtained by taking the average of A_4 as 3.00. From this value, CI was obtained as 0. For CR calculation, RI value for the three criteria was taken as 0.52 (ref. 25) and CR obtained as 0. This value is less than 0.1, indicating that the weights are consistent. The results show that the tollbooth operator's capability achieves the highest weight (0.51) and thus rank 1 compared to service time and safety. Service time was found to be less important than the tollbooth operator's capability, thus occupying the second position in the hierarchy. In the present study, service performance of the tollbooth operators is a superset, whereas their capability, service time and safety are the subsets, referred to as level 1 criteria (Figure 5). The subsets were compared pairwise to obtain the weights, according to the procedure given by Saaty[25]. Further, the sub-criteria (level 2) were compared pairwise to obtain their weights. After careful observations and comparison of the main criterion (level 1) weights, it can be concluded that the tollbooth operator's capability as a subset affects the superset more, i.e. the service performance of tollbooth operator. Hence, from Table 9, it can be concluded that the most important criterion for enhancing service performance is the capability of the tollbooth operators' potential. As a result, while developing policies, tollbooth managers (concessionaire) should consider the capability/potential of tollbooth operators. The tollbooth operator's service performance is depicted in eq. (9).

$$\text{Service performance} = 0.08 * \text{service time} + 0.51 * \text{capability} + 0.41 * \text{safety}. \quad (9)$$

Tables 10–12 describe the sub-criteria-wise calculations for determining priorities. From Table 10, it can be observed that collectively the highest weights are given to toll rate

Table 10. Combined relative importance matrix for sub-criteria in criterion 1 (service time)

	$A_{1'}$									Weights	
Matrix	Type of vehicle	Type of lane	Seat height	Toll rate	Queue length	Leader–follower pair	Driver behaviour	Type of journey	Extra attendant	A_2	Rank
Type of vehicle	1.00	0.25	0.72	0.18	0.18	0.26	0.26	1.00	1.01	0.04	7
Type of lane	4.02	1.00	3.69	0.88	0.84	1.16	0.95	3.91	3.36	0.16	3
Seat height	1.40	0.27	1.00	0.28	0.30	0.56	0.50	2.14	1.39	0.06	6
Toll rate	5.58	1.14	3.61	1.00	1.44	4.65	2.61	2.60	2.82	0.22	1
Queue length	5.51	1.19	3.36	0.69	1.00	3.53	3.40	4.33	4.53	0.22	1
Leader–follower pair	3.92	0.86	1.79	0.21	0.28	1.00	0.55	3.49	2.90	0.10	5
Driver behaviour	3.88	1.05	2.02	0.38	0.29	1.81	1.00	4.89	2.70	0.13	4
Type of journey (single, double, local pass)	1.00	0.26	0.47	0.38	0.23	0.29	0.20	1.00	2.02	0.04	7
Extra attendant	0.99	0.30	0.72	0.35	0.22	0.34	0.37	0.50	1.00	0.04	7

Note: Consistency check. CR = 0.065 < 0.1 → matrix is consistent.

Table 11. Combined relative importance matrix for sub-criteria in criterion 2 (capability)

	A_1					Weights	
Matrix	Training given	Shift timing	Number of breaks	Ergonomics of tollbooth	Health condition	A_2	Rank
Training given	1.00	3.66	3.03	3.28	2.22	0.42	1
Shift timing	0.27	1.00	0.84	0.94	1.93	0.15	3
Number of breaks	0.33	1.20	1.00	1.65	3.73	0.21	2
Ergonomics of tollbooth	0.30	1.06	0.61	1.00	1.98	0.14	4
Health condition	0.45	0.52	0.27	0.50	1.00	0.09	5

Note: Consistency check. CR = 0.053 < 0.1 → matrix is consistent.

Table 12. Combined relative importance matrix for sub-criteria in criterion 3 (safety)

	A_1					Weights	
Matrix	Size of cabin	Pure oxygen provision	Air pollution	Emergency exit	Safety uniform/ environment	A_2	Rank
Size of cabin	1.00	1.28	2.48	2.41	1.38	0.23	1
Pure oxygen provision	0.78	1.00	1.87	1.85	1.38	0.19	2
Air pollution	0.40	0.54	1.00	2.14	0.82	0.12	4
Emergency exit	0.42	0.54	0.47	1.00	1.32	0.10	5
Safety uniform/environment	0.72	0.73	1.22	0.76	1.00	0.13	3

Note: Consistency check. CR = 0.013 < 0.1 → matrix is consistent.

and queue length. Toll rate exchange and queue length observed at a tollbooth significantly affect the behaviour of the tollbooth operators, and thus service time. Hence, it is advised that the toll rates should be rounded to the nearest rupee in multiples of five[3].

Table 11 shows that the tollbooth operators' training is the most important criterion for their service performance. Thus, proper training should be given to the tollbooth operators, and assessment performed periodically to enhance their working performance.

From Table 12, it can be observed that cabin size is the most important criterion for the safety of tollbooth operators. Several tollbooth operators reported that their cabin and amenities in it significantly affect their safety and working efficiency. Collective results show that the other criteria such as pure oxygen provision, safety uniform, air pollution, etc. are given less priority than cabin size.

Table 13 shows the local and global weights for all the sub-criteria. The local weights were obtained in the combined matrix for the sub-criteria. The global weights were calculated by multiplying the sub-criteria weights with the main criteria weights. For example, for type of vehicle (i.e. sub-criterion 1 of the main criterion 1), the global weight = 0.037 (i.e. local weight) × 0.08 (i.e. criterion weight) = 0.003. The values in Table 13 show that the maximum global weight of 0.214 is obtained for training (sub-criterion 1 of main criterion 2), while a minimum of 0.03 is observed for the type of vehicle and an extra attendant (sub-criteria 1 and 9 of the main criterion 1). This is because criterion 1 has obtained lower weights compared to criterion 2 (Table 9).

The local weights (i.e. sub-criteria weights; Table 13) must be considered for deriving different operational performances under varying operating conditions. Thus considering the local weights, eq. (9) can be re-written as eq. (10)[34].

Service performance = 0.003 ∗ type of vehicle
+ 0.013 ∗ type of lane + 0.005 ∗ drivers' seat height
+ 0.018 ∗ toll rate + 0.018 ∗ queue length
+ 0.010 ∗ drivers' behaviour
+ 0.004 ∗ type of journey
+ 0.003 ∗ extra attendant + 0.214 * training given
+ 0.075 * shift timing
+ 0.106 * number of breaks
+ 0.074 ∗ ergonomics of tollbooth
+ 0.045 ∗ health condition
+ 0.095 ∗ size of cabin
+ 0.077 ∗ pure oxygen provision
+ 0.049 ∗ air pollution + 0.040 * emergency exist
+ 0.051 ∗ safety uniform/environment. (10)

Sensitivity analysis

Sensitivity analysis was carried out to demonstrate the effect of change in weights of the main criterion on the service performance of the tollbooth operators[27,51]. From the analysis, it was found that at level 1 the main criterion 2, i.e. capability of the tollbooth operators, had maximum weightage followed by main criterion 3, i.e. safety and least by main criterion 1, i.e. service time (Table 9). In the present study, sensitivity analysis was carried out to evaluate the effect on the overall service performance due to the change in weights of service time and capability of tollbooth operators. The base weight was taken from Table 9. Figure 6 *a* and *b* is a graphical representation of sensitivity analysis for service time and capability of tollbooth operators respectively. Equation (9) and the global and local weights from Table 12 were used for the analysis.

Figure 6 *a* shows that the tollbooth operators' overall performance increases as the service time weight increases. The weights of service time increased from 0 to 0.59 and the service performance increased from 0.00 to 0.14 (14% increase compared to the base value). Similarly, as the weight of the tollbooth operators' capability increases, it positively affects their service performance (Figure 6 *b*).

Conclusion

The present study uses the AHP method to determine priorities for enhancing the overall service performance of tollbooth operators. The tollbooth operators were interviewed with the help of a structured questionnaire framed for the said purpose. The results show that the capability of the tollbooth operators is the most important criterion affecting their service performance. Service time is affected the most by toll rate and queue length. In contrast, training

Table 13. Local and global weights for the sub-criteria

Particulars	Local weights	Global weights
Criterion-1 (service time)		
Type of vehicle	0.037	0.003
Type of lane	0.157	0.013
Seat height	0.060	0.005
Toll rate	0.217	0.018
Queue length	0.222	0.018
Leader-follower pair	0.097	0.008
Drivers' behaviour	0.126	0.010
Type of journey (single, double, local pass)	0.043	0.004
Extra attendant	0.042	0.003
Criterion-2 (capability)		
Training given	0.417	0.214
Shift timing	0.145	0.075
Number of breaks	0.207	0.106
Ergonomics of tollbooth	0.144	0.074
Health condition	0.087	0.045
Criterion-3 (safety)		
Size of cabin	0.234	0.095
Pure oxygen provision	0.191	0.077
Air pollution	0.120	0.049
Emergency exist	0.098	0.040
Safety uniform/environment	0.127	0.051

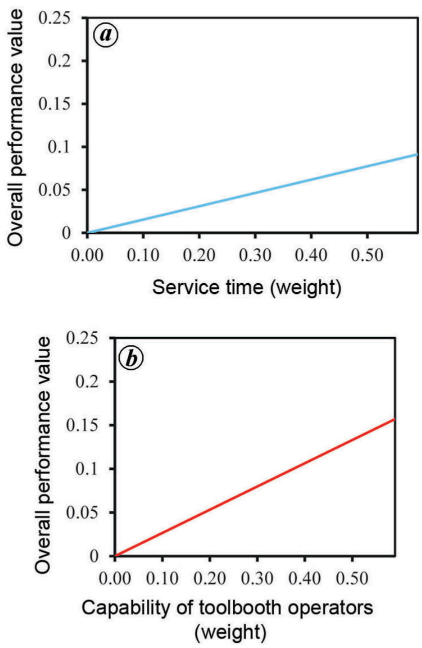

Figure 6. Sensitivity analysis: (*a*) service time and (*b*) capability of tollbooth operators.

given to the tollbooth operators has the highest priority according to the survey results. The cabin size is observed to be an essential parameter for the safety of the tollbooth operators.

Finally, sensitivity analysis was carried out to examine the effect of change in criteria weight on the tollbooth operators' overall service performance. With an increase in the weight of the capability of the tollbooth operators, their service performance level has also enhanced. Hence, it is recommended that training for the tollbooth operators, their cabin size and toll rate should be considered while framing policies so that there is an improvement in their service performance as well as in the overall performance of the toll plazas.

Importance of the work

The present work aims to identify the criteria affecting the performance of tollbooth operators using the AHP methodology. Though the use of the FASTag on the NHs is more than 90% (refs 52–54), most of the toll plazas on the SHs are still accepting cash transactions only[6]. Hence, it is necessary to improve the service performance of tollbooth operators, which ultimately increases the toll plaza capacity.

The findings of this study provide key insights for improving the service performance of the tollbooth operators in developing countries like India. According to the present study, the capability of tollbooth operators got maximum weightage followed by safety, and so the sub-criteria of capability of tollbooth operators and their safety should be considered. The first important aspect is training of the tollbooth operators for proper fare transactions and safety while working. The safety training should include knowledge about the procedures to be followed while working at the toll plazas, concerning lane crossing, lane closing, hazardous materials, emergencies, robbery, proper attire, review of drug and alcohol policies, irate customers, etc. There must be a provision of toll tunnels to reach the respective tollbooths while designing toll plazas. Further, the use of handheld 'stop' signs, safety jackets with retroreflective cover, antiskid shoes, provision of crosswalks and proper signage at the toll plazas are necessary for the safety of tollbooth operators. The provision of rumble strips, advanced signage and speed limits near the toll plazas can help decrease the speed of vehicles and thus improve the safety of the tollbooth operators.

Fatigue and body strain affect the tollbooth operators' capacity to work. So, they must be given suitable working hours with refreshment breaks. Further, it is observed in the field that the tollbooth operators do not have appropriate sitting arrangements. So they must be provided with good chair having a circular footrest and antifatigue mats. The provision of convex mirrors to observe the outgoing traffic and adjustable terminal height can help in toll transactions.

The tollbooth area suffers from high emissions (mostly carbon monoxides and particulate matter)[39] and noise which causes hearing problems. The management could provide noise barriers, pure oxygen supply, proper face masks and break timings so that continuous exposure of tollbooth operators to the contaminated environment can be minimized.

Thus, the measures suggested in the present study will help to enhance the service performance of tollbooth operators.

Limitations of the study

The present study deals with the service performance of tollbooth operators by considering exogenous and endogenous criteria, while collecting responses from the tollbooth operators. In future research, the reactions of the tollbooth operators and customers (toll road users) can be combined to define the service level of the toll plazas. The MADM approach with AHP can be utilized. In future analysis, the goal can be the level of service of the toll plazas, and the sub-criteria can include the criteria that are given in the present study along with the customer perspective criteria such as delays at the toll plaza, behaviour of tollbooth operators, time of reaching a toll plaza, i.e. rush/peak hours or non-peak hours, number of toll lanes available, type of payment method and the overall ambience of the toll plaza. In terms of the customers, the major criteria include socioeconomic and demographic variables, trip-related elements, and additional factors aimed at defining the service quality of toll plazas. In this study, data are taken from the western part of India. The study can be validated or compared with data from other regions to generalize the outcomes. Future studies can examine the effect of work shift, i.e. day/night shift, gender and age on the performance of the tollbooth operators.

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