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 toll¹². 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 stretch³. This heterogeneity causes variability in traffic behaviour⁴. 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 India⁵.

The toll payment on SHs is still done manually⁶. 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 interface⁵⁷. The MTC system still

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The performance evaluation of workers is a complex task which comprises various aspects and evaluation criteria. 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, 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. 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). Table 2 shows a comparison of different MADM methods describing the concept, methodology and their applications. The MADM methods are used for

<table>
<thead>
<tr>
<th>Source (ref. no.)</th>
<th>Country</th>
<th>Toll collection system</th>
</tr>
</thead>
<tbody>
<tr>
<td>8</td>
<td>Germany</td>
<td>Manual, automatic payment system, payment via the internet</td>
</tr>
<tr>
<td>55</td>
<td>Italy</td>
<td>Manual, credit card, automatic</td>
</tr>
<tr>
<td>9</td>
<td>United Kingdom</td>
<td>Manual, credit card and fuel card, automated payment system, congestion charging, and ultra low emission zone</td>
</tr>
<tr>
<td>56</td>
<td>Spain</td>
<td>Manual, credit card and shell card</td>
</tr>
<tr>
<td>57</td>
<td>Sri Lanka</td>
<td>Manual, automatic number plate recognition (ANPR), electronic toll collection (ETC), multi-lane free flow (MLFF)</td>
</tr>
<tr>
<td>58</td>
<td>Thailand</td>
<td>Manual, ETC</td>
</tr>
<tr>
<td>59, 60</td>
<td>China</td>
<td>Manual, semi-automatic manual collection, ETC and weight-based collection</td>
</tr>
<tr>
<td>61, 62</td>
<td>USA</td>
<td>Manual, ETC, high occupancy toll lanes (HOV), high occupancy toll lanes (HOT), congestion pricing</td>
</tr>
<tr>
<td>63</td>
<td>India</td>
<td>Manual, ETC</td>
</tr>
</tbody>
</table>
Table 2. Comparison of different multi-attribute decision making (MADM) methods

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

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. The degree of compensation can be partial (P), full (F), or non-compensatory. 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. The subjectiv

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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, mainly affected by vehicular emissions, as the vehicles are in idling mode in the tollbooth during toll transaction. 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. It is easy to understand and can be applied to decision-making problems. 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. 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.

### Toll plazas

Various studies were carried out on the performance of the tollbooth operators and service time was one of the criteria affecting it. 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.

### 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. 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

<table>
<thead>
<tr>
<th>Reference</th>
<th>Study area</th>
<th>Focus of the study</th>
<th>Key findings</th>
</tr>
</thead>
<tbody>
<tr>
<td>41</td>
<td>New York, USA</td>
<td>Delay at manual toll plazas</td>
<td>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.</td>
</tr>
<tr>
<td>42</td>
<td>Taiwan</td>
<td>Level of service (LOS) analysis of manual toll plazas</td>
<td>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.</td>
</tr>
<tr>
<td>83</td>
<td>Florida, USA</td>
<td>LOS at toll plazas</td>
<td>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’.</td>
</tr>
<tr>
<td>84</td>
<td>Canada</td>
<td>Analysing delay and environmental impacts of toll plazas using simulations</td>
<td>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.</td>
</tr>
<tr>
<td>35</td>
<td>Brazil</td>
<td>Evaluation of tollbooth workers’ performance</td>
<td>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.</td>
</tr>
<tr>
<td>7, 43</td>
<td>India</td>
<td>Analysis of service time of manually operated toll plazas</td>
<td>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.</td>
</tr>
<tr>
<td>85</td>
<td>India</td>
<td>Effect of FASTag penetration on queue delay</td>
<td>Simulation results showed that with full implementation of FASTag in India, the queue delay decreased on an average by 95%.</td>
</tr>
<tr>
<td>10</td>
<td>India</td>
<td>Effect of FASTag system in India</td>
<td>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.</td>
</tr>
</tbody>
</table>

### Rating Scale

<table>
<thead>
<tr>
<th>Definition</th>
<th>Rating</th>
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<tbody>
<tr>
<td>Equal importance</td>
<td>1</td>
</tr>
<tr>
<td>Moderate importance</td>
<td>3</td>
</tr>
<tr>
<td>Strong importance</td>
<td>5</td>
</tr>
<tr>
<td>Very Strong importance</td>
<td>7</td>
</tr>
<tr>
<td>Extreme importance</td>
<td>9</td>
</tr>
<tr>
<td>Intermediate values between two adjacent judgment</td>
<td>2, 4, 6, 8</td>
</tr>
</tbody>
</table>

#### Factors important according to you

Please tick (*) which resilience property/factor is more important

<table>
<thead>
<tr>
<th>Service Time</th>
<th>Capability</th>
<th>Safety</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1</td>
<td>2</td>
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<tr>
<td></td>
<td>3</td>
<td>4</td>
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<td>8</td>
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<td></td>
<td>9</td>
<td></td>
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</tbody>
</table>

Please indicate the level of importance

<table>
<thead>
<tr>
<th>Capability</th>
<th>Safety</th>
<th></th>
<th></th>
<th></th>
<th></th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
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<td>7</td>
<td>8</td>
<td>9</td>
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</tbody>
</table>

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
these toll plazas are located on major through f ares 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 tollbooth 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.

\(\text{Figure 3. Variation of service time.} \ a, b, \text{Box Plots showing vehicle class wise variation at (}a\text{) Bokarwadi Toll Plaza (BTP) and (}b\text{) GTP. (c) Probability density plot for the combined data at BTP and GTP.}\)
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\(^{44}\). 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\(^{5,7,36,43}\) (superset). The above-mentioned three main criteria consist of both exogenous and endogenous criteria. Exogenous criteria have external 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).
Then the relative importance matrix was found by interviewing the respondents (here, tollbooth operators) having work experience in the field.

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).

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

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

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 $e_{ij} = 1/e_{ij}$.

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

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

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

If CR > 0.1, then the combined matrix has to be developed. The procedure for finding the combined matrix as suggested in earlier studies has been adopted in the present study. Suppose the values given by the respondents...
Finally, sensitivity analysis was performed. Then the ranking was given according to the weights.

$$e_{ij} = \frac{1}{x_{ij}^{w_1} \times x_{ij}^{w_2} \times \ldots \times x_{ij}^{w_n}}$$  \hspace{1cm} (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 capability is 0.35.

$$w_1 = 0.69/5.21 = 0.13.$$  \hspace{1cm} (8)

Similarly, for the other two criteria, weights were calculated. Then $\lambda_{max}$ was obtained by taking the average of the $A_4$ matrix as 3.17. From this value, CI was obtained as 0.07. For CR calculation, the RI value for the three criteria was calculated. Then $\lambda_{max}$ was obtained by taking the average of the $A_4$ matrix as 3.17. From this value, CI was obtained as 0.07. For CR calculation, the RI value for the three criteria was calculated.

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

<table>
<thead>
<tr>
<th>Matrix</th>
<th>Service time</th>
<th>Capability</th>
<th>Safety</th>
<th>Geometric mean</th>
<th>$A_2$</th>
<th>$A_3$</th>
<th>$A_4$</th>
<th>Rank</th>
</tr>
</thead>
<tbody>
<tr>
<td>Service time</td>
<td>1</td>
<td>1/9</td>
<td>3</td>
<td>0.69</td>
<td>0.13</td>
<td>0.42</td>
<td>3.17</td>
<td>3</td>
</tr>
<tr>
<td>Capability</td>
<td>9</td>
<td>1</td>
<td>8</td>
<td>4.17</td>
<td>0.80</td>
<td>2.54</td>
<td>3.17</td>
<td>1</td>
</tr>
<tr>
<td>Safety</td>
<td>1/3</td>
<td>1/8</td>
<td>1</td>
<td>0.35</td>
<td>0.07</td>
<td>0.21</td>
<td>3.17</td>
<td>2</td>
</tr>
</tbody>
</table>

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

<table>
<thead>
<tr>
<th>Matrix</th>
<th>Type of vehicle</th>
<th>Type of lane</th>
<th>Seat height</th>
<th>Toll rate</th>
<th>Queue length</th>
<th>Leader–follower pair</th>
<th>Driver behaviour</th>
<th>Type of journey</th>
<th>Extra attendant</th>
<th>Geometric mean</th>
<th>$A_2$</th>
<th>$A_3$</th>
<th>$A_4$</th>
<th>Rank</th>
</tr>
</thead>
<tbody>
<tr>
<td>Type of vehicle</td>
<td>1</td>
<td>1/9</td>
<td>1/7</td>
<td>1/8</td>
<td>1/9</td>
<td>1/5</td>
<td>1/3</td>
<td>1</td>
<td>1/2</td>
<td>0.27</td>
<td>0.02</td>
<td>0.20</td>
<td>9.23</td>
<td>9</td>
</tr>
<tr>
<td>Type of lane</td>
<td>9</td>
<td>2</td>
<td>2</td>
<td>2</td>
<td>1</td>
<td>4</td>
<td>6</td>
<td>9</td>
<td>4</td>
<td>3.16</td>
<td>0.25</td>
<td>2.31</td>
<td>9.32</td>
<td>1</td>
</tr>
<tr>
<td>Seat height</td>
<td>9</td>
<td>1/2</td>
<td>1</td>
<td>1/3</td>
<td>1/2</td>
<td>2</td>
<td>3</td>
<td>7</td>
<td>3</td>
<td>3.17</td>
<td>0.25</td>
<td>2.66</td>
<td>10.68</td>
<td>5</td>
</tr>
<tr>
<td>Toll rate</td>
<td>9</td>
<td>2</td>
<td>2</td>
<td>5</td>
<td>1</td>
<td>6</td>
<td>4</td>
<td>3</td>
<td>5</td>
<td>5.21</td>
<td>0.07</td>
<td>0.67</td>
<td>10.22</td>
<td>5</td>
</tr>
<tr>
<td>Queue length</td>
<td>9</td>
<td>1/4</td>
<td>1/2</td>
<td>1/5</td>
<td>1/6</td>
<td>1</td>
<td>2</td>
<td>5</td>
<td>1</td>
<td>0.84</td>
<td>0.47</td>
<td>0.73</td>
<td>10.92</td>
<td>5</td>
</tr>
<tr>
<td>Leader–follower pair</td>
<td>9</td>
<td>1/3</td>
<td>1/7</td>
<td>1/5</td>
<td>1/5</td>
<td>1/5</td>
<td>1</td>
<td>2</td>
<td>5</td>
<td>0.34</td>
<td>0.03</td>
<td>0.17</td>
<td>6.50</td>
<td>7</td>
</tr>
<tr>
<td>Driver behaviour</td>
<td>9</td>
<td>1/5</td>
<td>1/3</td>
<td>1/5</td>
<td>1/5</td>
<td>1/5</td>
<td>1</td>
<td>5</td>
<td>1</td>
<td>0.47</td>
<td>0.04</td>
<td>0.38</td>
<td>10.26</td>
<td>8</td>
</tr>
</tbody>
</table>

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

<table>
<thead>
<tr>
<th>Matrix</th>
<th>Training given</th>
<th>Shift timing</th>
<th>Number of breaks</th>
<th>Ergonomics of tollbooth</th>
<th>Health condition</th>
<th>Geometric mean weights</th>
<th>$A_2$</th>
<th>$A_3$</th>
<th>$A_4$</th>
<th>Rank</th>
</tr>
</thead>
<tbody>
<tr>
<td>Training given</td>
<td>1</td>
<td>1/5</td>
<td>1/8</td>
<td>1/6</td>
<td>1/7</td>
<td>0.23</td>
<td>0.03</td>
<td>0.18</td>
<td>5.18</td>
<td>5</td>
</tr>
<tr>
<td>Shift timing</td>
<td>5</td>
<td>1</td>
<td>1/3</td>
<td>1/2</td>
<td>1/3</td>
<td>0.77</td>
<td>0.12</td>
<td>0.60</td>
<td>5.16</td>
<td>4</td>
</tr>
<tr>
<td>Number of breaks</td>
<td>8</td>
<td>3</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>2.70</td>
<td>0.40</td>
<td>2.19</td>
<td>5.42</td>
<td>1</td>
</tr>
<tr>
<td>Ergonomics of tollbooth</td>
<td>6</td>
<td>2</td>
<td>1/2</td>
<td>1</td>
<td>1/3</td>
<td>1.15</td>
<td>0.17</td>
<td>0.90</td>
<td>5.24</td>
<td>3</td>
</tr>
<tr>
<td>Health condition</td>
<td>7</td>
<td>3</td>
<td>1/3</td>
<td>3</td>
<td>1</td>
<td>1.84</td>
<td>0.27</td>
<td>1.51</td>
<td>2.51</td>
<td>5</td>
</tr>
</tbody>
</table>
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 $A_2$, $A_3$ 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. 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.

Table 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...
nearest rupee in multiples of five. It is advised that the toll rates should be rounded to the nearest rupee, and thus service time. Hence, 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 11 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 = 0.065 (i.e. criterion weight) × 0.08 (i.e. criterion weight) = 0.005. 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.

\[
\text{Service performance} = 0.003 \times \text{type of vehicle} + 0.013 \times \text{type of lane} + 0.005 \times \text{drivers’ seat height} + 0.018 \times \text{toll rate} + 0.018 \times \text{queue length} + 0.010 \times \text{drivers’ behaviour} + 0.004 \times \text{type of journey} + 0.003 \times \text{extra attendant} + 0.214 \times \text{training given} + 0.075 \times \text{shift timing} + 0.106 \times \text{number of breaks} + 0.074 \times \text{ergonomics of tollbooth} + 0.045 \times \text{health condition} + 0.005 \times \text{size of cabin} + 0.077 \times \text{pure oxygen provision} + 0.049 \times \text{air pollution} + 0.040 \times \text{emergency exist} + 0.051 \times \text{safety uniform/environment}.
\]  

(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 operators²⁷,⁵¹. 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 6a 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 6a 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 6b).

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...
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 only6. 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.

RESEARCH ARTICLES


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MinDOT, Minnesota tolling study report modern tolling practices and policy considerations. Minnesota Department of Transportation, 2018, pp. 1–106.


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