Driver’s Perceived Satisfaction at Urban Roundabouts—A Structural Equation-Modeling Approach

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Abstract: In recent years, the use of roundabouts in road networks has reflected a sustainable and modern solution for traffic intersections. Their implementation, integrated design, and proper evaluation are a necessity to achieve their beneficial results. According to the latest edition of the Highway Capacity Manual (HCM) and the Highway Capacity and Quality Service (HCQS), a comprehensive evaluation of a roundabout is based on the interchangeable use of the LOS (level of service) and QOS (quality of service). Both manuals describe the LOS criteria, which are the same as those currently used for unsignalized at-grade intersections, while the QOS methodological description and criteria are not specifically defined. The quality of service, which corresponds to road users’ perceived satisfaction, is determined by identifying and evaluating certain factors that have an impact on users. While the previous work on evaluating the quality of roundabouts is limited, this work aimed to present and evaluate the concept of QOS for urban roundabouts in Greece and to assess the factors that affect drivers’ perceived feeling of comfort. The methodology used for the research, included data collection via an on-line questionnaire addressed to the users of the Greek road network and a statistical analysis based on the performance of six latent variables named quality components (exploratory factor analysis). A structural equation model (SEM) was used to determine the causal relationship between primary factors and quality components. It was noted that the SEM cannot predict the travel behavior but it has ability to express relationships between unobserved and observed variables. The results of the revealed model are of great value for the development of: (a) a comprehensive conceptual framework of the QOS and (b) a critical analysis of the parameters that should be considered for the assessment of the QOS of a roundabout. Identifying the factors that influence road users’ perception in terms of safety and comfort (quality of service) leads to a better knowledge and understanding of the road network characteristics that are important to road users and that influence their behavior and level of satisfaction.

Keywords: factor analysis; urban roundabouts; perceived satisfaction; car drivers; structural equation modelling; quality of service

1. Introduction

In recent years the use of roundabouts in road networks has reflected a sustainable and modern solution for road traffic intersections. Roundabouts countermeasure the benefits of safety and traffic-flow quality [1–3]. In consequence, there is an increasing interest among consultants and transportation professionals, regarding their effective evaluation. The latest edition of the Highway Capacity Manual (HCM) [4] presents a method for evaluating a roundabout’s level of service in terms of operating performance, based on the standard calculation of the average control delay (volume/capacity) of vehicles. The same manual, as
well as the Highway Capacity and Quality of Service handbook (HCQS) [5], acknowledges the fact that an intergraded evaluation of a road infrastructure should include quality characteristics that reflect the user’s point-of-view. Moreover, the scientific research clearly indicates that the operational performance of a specific intersection type is influenced by a number of different factors, which contribute to the efficiency and usage of the intersection and the perceived satisfaction of the users [4–8]. All of these factors are expressed through the concept of “quality of service” i.e., the ability of a road facility to provide better service, as reflected by the needs and/or the perceived satisfaction of the road users [9–12].

2. Literature Review

The integration of user-based perceived information with standard engineering quantitative methods is relatively new. The need for this integration is emerging either by the introduction of three performance indicators [4,5], the measures of effectiveness (MOE) (which include degree of saturation, delay, queue length, and proportion and number of stops before a vehicle enters the intersection) or by the outcomes of research studies that are focused on the analysis and modelling of the factors that were related to: (a) design characteristics of the roundabout, such as roundabout size of intersection, left/right turn lane (depending on the driving regulations of the country), radius of deflection, deviation angle, markings and road signs, and pavement quality [10–12] and (b) analysis of the effects of different contributing factors on accident rating and/or injury severity. These results indicate factors in addition to the geometric, such as increased number of vehicles (congestion) [13–15], types of accidents at the intersection, bus involvement, presence of bicycles, accidents during darkness on unlit or poorly lit roads, local surroundings and landscaping, different road characteristics and traffic volumes, and number of lanes and their continuity, as well as the presence of traffic signals near the intersection [16–18].

Although roundabouts are very popular worldwide, there is limited literature that focuses on roundabout quality evaluation. However, in all available cases, researchers tended to follow similar procedures, expanded in two directions: (a) safety and (b) comfort. Daniels et al. (2010), examined the severity of crashes at roundabouts, in order to investigate which factors contributed to the severity of crashes or injuries. The researchers collected data from 1491 crashes on 148 roundabouts in Flanders-Belgium. They used logistic regression and hierarchical binomial logistic regression techniques to analyze data. The results showed that the presence of vulnerable users contributed to higher and more severe accident occurrence. Additionally, poor street lighting aggravated this effect during the hours of darkness [19,20]. Montella et al. (2011), investigated which were the most important crash contributory factors in 15 urban roundabouts located in Italy and, the interdependences between these. The identification of the factors was based on site inspections and statistical analysis showed that there were numerous contributory factors related to the road and environment deficiencies but not related to the road user or to the vehicle. Further analysis of the results indicated that all factors were associated with the entry geometric design elements, signs, and markings [14]. Distefano et al. (2019), published the results of an on-line survey, aimed at detecting a roundabout’s geometric characteristics—which may influence driver safety perception while maneuvering at the entry, circulation, and exit in urban roundabouts. Data collected from a sample of 1649 participants were analyzed by factor analysis and the results showed that roundabout drivers’ safety perception originates from geometric characteristics. Drivers prefer simple configurations (single lane on circulatory roadway), complete vertical and horizontal signage, and clear guidance, (geometric coherence of the consecutive elements) [7].

Regarding QOS related to roundabouts, the QOS of urban roundabouts was assessed and presented based on the driver’s perception and the geometric characteristics and traffic-flow conditions of the roundabout. The researcher performed a field origin–destination survey of various urban roundabouts, with the aim of collecting data on the degree of drivers’ satisfaction under various traffic-flow conditions. The results of the research showed that the quality of service perception of urban roundabouts is influenced by sev-
eral factors including approach level of service, pavement quality, pavement marking, pedestrian activity, clarity of road signs, and presence of landscaping. Regression-analysis models were structured to determine urban a roundabout’s degree of satisfaction [20–26]. Kittelson and associates, (2017), conducted an extended review, for the Florida department of transportation, where they initiated the best practices and methodologies for the evaluation of the level and quality of service for different modes and road infrastructures. They found that unlike traditional intersections, roundabout evaluation requires additional evaluation tools and an outreach to help users understand how they will navigate the roundabout (vertical and horizontal signage) [22]. Damaskou et al. (2020), investigated which factors influence QOS in road safety at urban roundabouts, based on drivers’ perception. The tool used was a web-questionnaire, filled out by about 1100 participants. Within the framework of the research, a statistical analysis methodology was developed and implemented, creating a regression-analysis model. The model relates the key quality factors that play a significant role in the safety parameters of a roundabout [10].

In all the aforementioned surveys, the procedures followed were based on data collected directly from the users, who were asked to identify and evaluate variables related to the quality of road intersections, in an attempt to capture data that accurately reflected real-world traffic conditions. The most recent methodologies have included the use of on-line questionnaires [15,16], observation [17], video recordings [18,19], and post-trip personal interviews [20–22].

The objective of this paper was to provide some insight into the factors affecting quality of service at urban roundabouts. An on-line survey addressed to Greek road users was performed. Out of 1011 questionnaires, a final sample of 778 participants was selected (a percentage of 77% of the sum of the questionnaires). The participants who did not complete the questionnaire or the ones that gave uncertain answers (e.g., “I don’t know”) were excluded. Moreover, respondents without a driving license were also excluded. Most of the participants with a driving license (96.4%) said that they traveled through a roundabout at least once a week. Given that the aim of the study was to investigate the way that drivers perceived service quality on roundabouts, for those with a driving license, the analysis was restricted to the different characteristics of the users and their driving experience on roundabouts. The primary dataset was created with answers of the respondents to the all the sections of the questionnaire. The answers to the questions in Sections A–C (as described in Section 3.1) have already been used by the authors for a study which aimed to identify the factors that influence quality of service in road safety at urban roundabouts [10,11].

An ordered logit model was used to express the satisfaction of the respondents while they navigated through an urban roundabout. The factors were analyzed descriptively and then a factor analysis was performed, so as to reveal any latent correlation between them. Finally, a linear regression analysis model was used to describe the users’ (drivers) feeling of comfort.

The paper is structured in three different sections. In the first introductory section, an overview of the factors affecting roundabout users’ perception is presented. The second section includes a description of the adopted methodology, including a description of the questionnaire’s design and dissemination. Then, the techniques of the data statistical analysis are presented and the results of the models are interpreted. Finally, conclusions are drawn about perspectives of future research and the potential for implementing a conceptual framework on roundabout evaluation that would include quality factors.

3. Materials and Methods

3.1. Data Collection and Processing

To examine the influence of key factors of the urban roundabout environment in terms of driver satisfaction, an on-line survey addressed to Greek road users was performed. Using the framework of a questionnaire based on a literature review, a web-questionnaire of 25 items was designed in order determine the opinions of the selected Greek drivers.
Extended analysis of the questionnaire is presented in the research of the authors of [10,11]. The questionnaire was divided into four distinct sections.

Section A: this section was dedicated to the socio-demographic profiles of the respondents (gender, age distribution, marital status, education, and occupation);

Section B: this section reflected the users’ “familiarity or unfamiliarity” with roundabout use based on specific questions;

Section C: in this section, understanding of priority rules, while navigating through a roundabout was examined;

Section D: the fourth section of the questionnaire aimed to qualitatively evaluate different factors of a roundabout’s environment.

The final sample was almost equally divided between men and women (57.1% men and 41.9% women). Most of respondents were aged between 26 and 55 (65.6%). A significant percentage of the participants were aged between 26 and 35 (19.9%) [11]. The travel mode most frequently used was privately owned car or motorcycle, followed by public-transport users. There was a low but not negligible percentage of cyclists, while only 5.52% of respondents were more likely to move on foot. The majority of the participants (95.57%) traveled through a roundabout at least once per week.

The analysis methodology was developed and implemented based on exploratory factor analysis, a regression model, and, finally, the adoption of a structural equation model that expressed the contributory factors of the users’ feelings of comfort. Based on the authors’ critical literature review, the recommendations of the HCM 2010, and an evaluation of the characteristics of the Greek road network, eleven factors were finally considered to be the most critical. These factors were accepted and evaluated by roundabout users. An exploratory factor analysis was performed in order to simplify data and determine which factors were highly correlated and how many common factors were necessary to give an adequate description of the data. The last step of the analysis included the implementation of a structural equation model (SEM), aimed at quantifying the influence of each latent variable. The aim of this process was the assessment of service quality in terms of drivers’ perceived satisfaction with respect to their experience through an urban roundabout.

Questions of the Section D required drivers to evaluate, positively or negatively, eleven preselected factors, in order to determine their feelings of perceived satisfaction. The selection of the factors was based on literature review [10–13]. The criteria for the selection of the specific factors were: (a) frequency in international research studies aimed at defining road user perceived satisfaction, [27–29], (b) measures of effectiveness for improved level-of-service definition [9,14–16], and (c) the critical point-of-view of the authors.

Survey participants rated the factors according to their importance by using a Likert “1–5 scale” where ‘1’ indicated that the factor was unimportant and ‘5’ indicated that the factor was very important. Prior to the actual implementation of the questionnaire, it went through a pilot round with a small group of random participants and was then revised. This was considered a necessary preparatory step, in order to test the clarity of the questions and determine whether all the respondents in the pilot round were capable of following and answering the questions, as well as to provide an indication of the effectiveness of the study.

The online survey was created with the “Monkey Survey” online platform. Then, it was made available online randomly, through web sites, targeted e-mails and SMS messaging. The purpose of the survey was to collect as many answers as possible from drivers in Greece.

Given that the aim of the study was to determine the relationship between the quality characteristics of roundabouts and the way in which they influence roundabout car drivers, analysis of the results of the two questions of the questionnaire is explored in Section D and is presented in Table 1. The respondents to these questions were not referring to specific urban roundabouts but, rather, the drivers expressed their perceived feeling, based on their driving experience on urban roundabouts in general.
Table 1. Questions referring to the QOS of urban roundabouts.

| Questions                                                                 | 1. Congestion | 2. Road surface quality | 3. Landscaping | 4. Pedestrian activity | 5. Bus activity close to the roundabout | 6. Road signage | 7. On-street parking | 8. Pavement markings | 9. Lane change | 10. Street lighting | 11. Presence of bicycles |
|---------------------------------------------------------------------------|----------------|--------------------------|----------------|------------------------|------------------------------------------|----------------|----------------------|----------------------|----------------|----------------------|------------------------|
| 1. Rank the following factors that affect trip quality *                  |                |                          |                |                        |                                           |                |                      |                      |                |                      |                        |
| (1: it is not important . . . . . . 5: it is extremely important)        |                |                          |                |                        |                                           |                |                      |                      |                |                      |                        |
| 2. What is your overall degree of satisfaction when navigating through    | 1. Very satisfied |                        |                |                        |                                           |                |                      |                      |                |                      |                        |
| urban roundabouts vs. a common intersection?                             | 2. Satisfied   |                          |                |                        |                                           |                |                      |                      |                |                      |                        |
|                                                                            | 3. Neither satisfied nor dissatisfied |                |                |                        |                                           |                |                      |                      |                |                      |                        |
|                                                                            | 4. Not satisfied |                          |                |                        |                                           |                |                      |                      |                |                      |                        |
|                                                                            | 5. Dissatisfied |                          |                |                        |                                           |                |                      |                      |                |                      |                        |

3.2. Methodology

In an attempt to better understand the relationship between quality factors and perceived service quality while navigating in an urban roundabout, the method selected to conduct this analysis was the multivariate statistical analysis of structural equation modeling (SEM). The specific technique was the combination of factor analysis and multiple regression analysis, and it was used to analyze the structural relationship between measured variables and unobserved constructed components. This method is widely preferred by researchers of social behavioral because (a) it identifies possible latent constructs inside the data and (b) it estimates the multiple and interrelated dependence in a single analysis [21–26]. In this analysis, there are two types of variables—endogenous and exogenous. Endogenous variables are equivalent to dependent variables and influence the independent variables [27–29]. More specifically, endogenous variables have values that are determined by other variables in the system (these “other” variables are called exogenous variables). Exogenous latent variables are independent variables and they cause fluctuations in the values of other latent variables in the model, (i.e., the characteristics of the sample) while endogenous latent variables or dependent variables are influenced by the exogenous variables in the model, either directly or indirectly by causing fluctuation [30,31]. More specifically, exploratory factor analysis (EFA) was used in this research primarily in order to investigate the data set collected and identify the relationships between the quality factors [4,5,32–35]. The EFA method was selected due to the fact that relative theory and data were still under investigation and evaluation of the maximum amount of variance was required. Additionally, EFA is considered as a more appropriate statistical method for the analysis and description of human abilities connected to variables not measured directly [5,24,27,32]. In the current research, we attempted to investigate the driver’s overall unobserved comfort feeling through this type of analysis. This information can provide some insights for transportation engineers, urban planners, and decision-makers concerning improved conditions and can suggest measures that could improve roundabouts’ operational and safety performance.

4. Results

Factor Analysis

In multivariable statistics exploratory factor analysis, (EFA) is a method used to identify the existence of collinearity before performing any linear regression analysis (e.g., structural equation modeling) and also to identifying statistically insignificant variables, with the aid of the statistical package IBM SPSS v.23.0, AUTH, Thessaloniki, Greece.
This specific method was employed in order to reduce the number of research variables to fewer components and determine the share the intercorrelated effect of the variables. The preliminary computation carried out suggested that internal cohesion of the data was suitable and the sample size was adequate for expression of the correlation between the research variables. More specifically, the KMO = 0.838 value was higher than 0.800. This implied that our dataset was able to proceed to further analysis. Bartlett’s statistic was also significant at the level of \( p = 0.01 \) (Table 2) and the null hypothesis concerning the identical matrix was rejected. The explorative factor analysis operations could therefore be fulfilled. The results described in Table 2, led to the conclusion that the EFA satisfied the fragment criteria (KMO > 0.5 and Bartlett’s test of sphericity < 0.05) and that the sample was adequate for further analysis.

Table 2. Tests of goodness-of-fit.

| KMO and Bartlett’s Test |   |
|------------------------|---|
| Kaiser–Meyer–Olkin measure of sampling adequacy | 0.838 |
| Bartlett’s test of sphericity |   |
| Approx. \( \chi^2 \) | 1823,785 |
| df | 55 |
| Sig. | 0.000 |

The next step of the process was the extraction of the number of generated factors. The specific number depended on the variance of the variables. For this purpose, the Kaiser criterion for choosing the most efficient number of factors generated according to the extracted the eigenvalues was used and only three factors were extracted. The Kaiser criterion showed that only those factors with eigenvalues higher than one (1) could be extracted (Figure 1).

Figure 1. Eigenvalue scree plot.

Factor analysis is based on the basic principle that the outcome factors are independent and uncorrelated. This prerequisite was achieved through the calculation of the weighing scores of the extracted factors, by using Anderson’s method. The next step consisted of the explanation of the total variance of data of the generated factors. The total variance is described in Table 3. The total cumulative variance explained from these three factors was only 55.95%. In that case the first hypothesis of the Kaiser criterion was rejected and a total number of generated factors that explained a higher cumulative percentage proceeded. From the following table we can see that the first component had a leading role.
to our analysis, explaining a percentage higher than 35% (35.203%) while the other five in ascending order reached values of less than 10%.

Table 3. The extracted factors together with their eigenvalues, percentage of variance, and cumulative percentage.

| Component | Initial Eigenvalues | Extraction Sums of Squared Loadings | Rotation Sums of Squared Loadings |
|-----------|---------------------|-------------------------------------|----------------------------------|
|           | Total | % of Variance | Cumulative % | Total | % of Variance | Cumulative % | Total | % of Variance | Cumulative % |
| 1         | 3872  | 35.203       | 35.203       | 3872  | 35.203       | 35.203       | 1737  | 15.794       | 15.794       |
| 2         | 1174  | 10.674       | 45.877       | 1174  | 10.674       | 45.877       | 1642  | 14.929       | 30.223       |
| 3         | 1109  | 10.078       | 55.955       | 1109  | 10.078       | 55.955       | 1615  | 14.685       | 45.408       |
| 4         | 0.865 | 78.64        | 63.818       | 0.865 | 78.64        | 63.818       | 1201  | 10.916       | 56.324       |
| 5         | 0.800 | 72.76        | 71.095       | 0.800 | 72.76        | 71.095       | 1141  | 10.376       | 66.700       |
| 6         | 0.657 | 59.74        | 77.069       | 0.657 | 59.74        | 77.069       | 1141  | 10.369       | 77.069       |
| 7         | 0.631 | 57.35        | 82.804       |       |              |              |       |              |              |
| 8         | 0.530 | 48.17        | 87.621       |       |              |              |       |              |              |
| 9         | 0.508 | 46.21        | 92.242       |       |              |              |       |              |              |
| 10        | 0.462 | 42.01        | 96.443       |       |              |              |       |              |              |
| 11        | 0.391 | 35.57        | 100.000      |       |              |              |       |              |              |

Extraction method: principal component analysis.

Repeating the process with six generated factors led to an efficient value that explained 77.069% of the variance. Based on this value, six factors with eigenvalues above one were extracted and organized. The final factors were the components. For the six derived components, the matrix for total variance was examined. Among the prerequisite properties for acceptance for those components were independency and uncorrelation. Aspects satisfied by using Anderson’s method were processed in order to create a valid orthogonal factor model. Those properties were stated as components to be uncorrelated, i.e., they should have a mean value equal to zero and the covariance matrix should be equal to the identity matrix. Using nonparametric techniques for correlation analysis and the t-test for mean values we observed that the prerequisite properties were satisfied. The next step was to describe the variables that comprised the new components, with their relative weightings. Table 4 describes the result of the relationships among the quality factors that generated the new components. The highest values represented by QOS factors in the generated components explains the nature of the last one.

Table 4. Rotated component matrix of scores of QOS factors to the generated components.

| Component               | 1   | 2   | 3   | 4   | 5   | 6   |
|-------------------------|-----|-----|-----|-----|-----|-----|
| Congestion              | 0.083 | 0.017 | 0.067 | 0.064 | 0.125 | 0.095 |
| Road pavement quality   | 0.072 | 0.077 | 0.008 | 0.035 | 0.328 | 0.172 |
| Landscaping             | 0.071 | 0.016 | 0.050 | 0.102 | 0.261 | 0.091 |
| Pedestrian activity     | 0.012 | 0.103 | 0.133 | 0.140 | 0.122 | 0.106 |
| Bus activity close to the roundabout | 0.671 | 0.394 | -0.069 | 0.067 | 0.077 | 0.271 |
| Clarity of road signs   | 0.176 | 0.595 | 0.363 | -0.13 | 0.343 | 0.075 |
| On-street parking       | 0.143 | 0.818 | 0.068 | 0.096 | 0.109 | 0.004 |
| Pavement markings       | 0.116 | 0.622 | 0.364 | 0.442 | 0.034 | -0.021 |
| Lane change             | 0.170 | 0.171 | 0.297 | 0.241 | -0.124 | 0.296 |
| Street lighting         | 0.094 | 0.167 | 0.537 | 0.017 | 0.441 | 0.043 |
| Presence of bicycles    | 0.713 | 0.056 | 0.448 | 0.058 | 0.101 | 0.047 |

Extraction method: principal component analysis. Rotation method: Equamax with Kaiser normalization. Rotation converged in 18 iterations. Positive Correlation, Negative Correlation.

The factors are named according to their nature (Table 4).
The components and the observed variables that explained each of them could be characterized in the same group based on their meaning. The six components can be summarized and tentatively labelled as follows:

**Component 1—“Allocation of different kinds of users”:** This group includes “Pedestrian activity”, “Bus activity close to the roundabout”, and “Presence of bicycles”. This component brings together elements of the questionnaire related to access management and safety, namely the tendency to incorrectly use the priority rules of roundabouts in the presence of oncoming vehicles, the correct allocation of different users, and keeping adequate distances between other activities.

**Component 2—“Clarity and easy of recognition”:** The second group consists of “Clarity of road signs”, “On-street parking”, and “Pavement markings”. This component outlines the need for controlled guidance. All previous variables must be considered during the design and operational stage of the intersection. The signing process ensures signs are seen accurately by drivers and within the appropriate time frame and it maintains road safety. On-street parking is not allowed on or close to roundabouts, because they limit space and visibility. Another aspect of this specific component is lack of uniformity in terms of priority rules. In Greece, according to the “Road Traffic Code”, the vehicle moving into the roundabout should give priority to the ones entering, unless a stop sign is located at the entrance way. This fact caused some confusion in drivers’ behavior.

**Component 3—“Maneuverability”:** The third group appeared to have an impact on “Lane change” and “Street lighting”. This component as is related to aspects of maneuverability especially during the hours of darkness, factors correlated to drivers’ space perception and clear visibility.

The remaining factors affected only one variable.

**Component 4—“Congestion”:** This component was negatively influenced by “pavement markings” and “Street lighting” and was correlated to the overall operational performance of a roundabout, in terms of capacity and delay measurements.

**Component 5—“Road pavement quality”:** This component was negatively influenced by the “Lane change” factor. The quality of road at roundabouts is of great importance. In general, there are two causes of the roundabout structural defects: improper road structure and poor maintenance during the use of roundabout. Both of these influence driving speed and driving trajectory, as well as providing the possibility of riding up onto kerbs and blocking pavements within the roundabout zone, increasing the chances of damage to the roundabout.

**Component 6—“Landscaping”:** The last factor was not considered as very important by the drivers, possibly due to the fact that roundabouts in Greece are lacking in distinguishing features and/or the aesthetic design of the central island and the splitter islands (as described in HCM).

5. Model Development

Based on the results of the exploratory factor analysis, the next step included the construction of the SEM, performed with the aid of the SPSS package. Six latent variables/components were used to construct the final structural equation model. The descriptive statistics of the components are described in Table 5.

According to the results of the factor analysis, all factors used were independent and not correlated to each other. According to the measures that provide consistency and acceptability of the model, Pearson linear correlations of QOS and the components with non-zero index values under the level of significance of significance $\alpha = 0.05$ were calculated, as described in Table 6.
Table 5. Descriptive statistics of the components.

| Component | Mean Statistic | Std. Error | 95% Confidence interval for Mean |
|-----------|----------------|------------|----------------------------------|
| Component 1 | 0.0164057 | 0.04071714 | -0.0635741 to 0.0963856 |
| Component 2 | -0.0056712 | 0.04173457 | -0.1107138 to 0.0876495 |
| Component 3 | -0.0293790 | 0.04140693 | -0.1107138 to 0.0876495 |
| Component 4 | 0.0102796 | 0.04278569 | -0.0737635 to 0.0943226 |
| Component 5 | -0.0129382 | 0.04288639 | -0.0971791 to 0.0713026 |
| Component 6 | -0.0060800 | 0.04263420 | -0.0898255 to 0.0776654 |

Median Statistic | 0.0641141 | 0.0963856 | 0.0185680 |

Variance Statistic | 0.915 | 0.95663614 | 0.98054029 |

Std. Deviation Statistic | 0.915 | 0.95663614 | 0.98054029 |

Minimum Statistic | -3.32544 | -3.32544 | -3.32544 |

Maximum Statistic | 2.26295 | 2.26295 | 2.26295 |

Range Statistic | 5.58839 | 6.16631 | 6.06614 |

Skewness Statistic | -0.415 | -0.415 | -0.415 |

Kurtosis Statistic | -0.048 | -0.048 | -0.048 |

The final model constructed was based on a train set equal to the 90% of the sample (\( n = 552 \)) and a test set equal to the remaining 10%. The summary values of the model are described analytically in Table 6. We obtained an R-squared value of 0.933, a value high enough for goodness-of-fit and the error followed the assumption of homoscedasticity according to the Durbin–Watson test (Sig. = 0.00+e<0.05) under a level of significance equal to \( a = 0.05 \) (Table 7).

Table 8 describes the coefficients derived for the multivariate linear model. We found that under a significance level of \( a = 0.05 \) every single component had statistically significant non-zero scores, as mentioned before in ANOVA Table, and every single component had an impact to our model. Looking at the variation inflation factor (VIF) index, for which values near to 1 mean that there is lack of collinearity, a case that is prerequisite, we see that each component had a positive effect on our model with the highest belonging to Component 2 and Component 1 with scores of 0.310 (Sig. = 0.00+e<0.05) and 0.255 (Sig. = 0.00+e<0.05), respectively.
Table 7. Durbin–Watson test.

| Model | R   | R Square | Adjusted R Square | Std. Error of the Estimate | R Square Change | F Change | df1 | df2 | Sig. F Change | Durbin–Watson |
|-------|-----|----------|-------------------|-----------------------------|----------------|----------|-----|-----|---------------|---------------|
| 1     | 0.490 | 0.241  | 0.239  | 0.5421  | 0.241  | 157.439  | 1   | 497 | 0.000         |               |
| 2     | 0.637 | 0.406  | 0.404  | 0.47996 | 0.165  | 138.047  | 1   | 496 | 0.000         |               |
| 3     | 0.750 | 0.562  | 0.559  | 0.41250 | 0.156  | 176.489  | 1   | 495 | 0.000         |               |
| 4     | 0.849 | 0.721  | 0.719  | 0.32945 | 0.159  | 282.008  | 1   | 494 | 0.000         |               |
| 5     | 0.931 | 0.867  | 0.866  | 0.22787 | 0.146  | 539.618  | 1   | 493 | 0.000         |               |
| 6     | 0.997 | 0.993  | 0.993  | 0.05091 | 0.126  | 9384.011 | 1   | 492 | 0.000         | 1859          |

a. Dependent variable: QOS.

Table 8. Table of coefficients of components in multivariate linear model.

| Coefficients a | Model | Unstandardized Coefficients | Standardized Coefficients | t | Sig. |
|----------------|-------|-----------------------------|--------------------------|---|-----|
|                |       | B  | Std. Error | Beta |       |       |
| (Constant)     |       | 3.675 | 0.002 | 1610.709 | 0.000 | 3.671 | 3.680 |
| Component 2    |       | 0.310 | 0.002 | 0.514 | 140.057 | 0.000 | 0.306 | 0.315 | 0.999 | 1.001 |
| Component 3    |       | 0.253 | 0.002 | 0.406 | 110.561 | 0.000 | 0.244 | 0.257 | 0.999 | 1.001 |
| Component 4    |       | 0.255 | 0.002 | 0.408 | 110.946 | 0.000 | 0.250 | 0.259 | 0.999 | 1.001 |
| Component 5    |       | 0.241 | 0.002 | 0.396 | 107.924 | 0.000 | 0.237 | 0.246 | 0.999 | 1.001 |
| Component 6    |       | 0.235 | 0.002 | 0.382 | 103.922 | 0.000 | 0.230 | 0.239 | 1.000 | 1.000 |

a. Dependent variable: QOS.

The model was formed according to the equation:

\[ QOS = 0.255 \times C1 + 0.310 \times C2 + 0.253 \times C3 + 0.241 \times C4 + 0.235 \times C5 + 0.215 \times C6 + 3.675 \]

The regression model was constructed based on 90% of the sample set, leaving the remaining 10% for testing. For that purpose, the model was tested on the original and the predictive values. The predicted values were formed by a variable named predictions of values. The expected result had a strong linear correlation among these values and the original ones. The results are described in Table 9. It can be seen that Pearson linear correlation index had a strong non-zero value of 0.997 (Sig. = 0.00+e<0.05), a fact that confirms validation of the model.

Table 9. Table of correlations among QOS and predictive values from linear regression model.

|                                   | QOS       | Prediction of Variables |
|-----------------------------------|-----------|-------------------------|
| Pearson correlation               | QOS       | Prediction of variables |
| Sig. (1-tailed)                   | QOS       | Prediction of variables |
| N                                 | QOS       | Prediction of variables |

6. Conclusions

The purpose of this specific research was to provide insight into the factors affecting quality of service at urban roundabouts. The methodology adopted seeks to identify the satisfaction of drivers while navigating through an urban roundabout by attributing
weighting factors to a number of variables. The methodology included an on-line survey addressed to Greek road users. A final database of 577 participants was obtained.

Then, a factor analysis was performed, in order to uncover possible hidden correlations between various quality factors selected from literature review, human perceived satisfaction, and an understanding of the local conditions.

Based on the above remarks, in the current survey, the total variance criterion was considered as the optimum criterion, used with a threshold of 75%. In addition to the above explanation (and also due to the low percentage (55.955%) of the total variance being explained by a three-factor model), each of the factors “Congestion”, “Road pavement quality”, and “Landscaping”, presented low correlation levels with the rest of the factors of the survey, while the remaining factors appeared to have a stronger intercorrelation (resulting to the formation of the first three components).

Furthermore, a generalized regression model aimed at assessing the QOS of urban roundabouts based on the drivers’ perception through the latent factors, was estimated.

More attempts were considered with the selection of four and five factors for the model. The results were similar to the ones derived with three-factor analysis, meaning that the total variance criterion was still lower than 70% (2/3 of the total sample).

As a result, a six-factor model was considered. The results of the EFA–PCA method were tested with the Equamax rotation method and the Anderson–Rubin score estimation method, basically creating new individual components (due to their high scores in each respective component) and we reduced the bias obtained from a three-, four-, or five-factor model. This result was strengthened by the fact that in a three-, four-, or five-factor model the factors “Congestion”, “Road pavement quality”, and “Landscaping” would belong to components with other factors with which they had low correlation levels and negative components resulting to low internal-consistency levels (Table 4).

This model revealed that the most effective factors influencing the quality of service rating at urban roundabout and the type of linear regression analysis used were, in order, “Clarity of signage and easy of recognition” (weight 0.310), “Allocation of different kinds of users” (weight 0.255), and “Maneuverability” (weight 0.253). The considerations derived from the final modeling included the respondents’ opinions regarding the perception of comfort. Roundabout drivers perform their driving actions and decisions as a sequence of maneuvers which are reactions to the various indications they receive and perceive from both the intersections’ geometry and the local environment. Their feeling of comfort originates from the complete and timely perception of the way that they will use the roundabout. The second component implies that drivers get distracted by the presence of other users, especially when they are not allocated properly. Interference of different users at an intersection results to operational deficiencies, due to change in speed limits, operational speed, delays, and queues. Finally, the results have shown the importance of maneuverability. It is well known that single-lane roundabouts are the most preferred by drivers because they have a simpler geometry. However, maneuverability in double- or double+-lane roundabouts can be optimized by the geometric characteristics of the roundabout’s design elements.

The adoption of the specific approach used consisted of a first attempt to provide insight into the perceived satisfaction of different respondents’ driving experiences on urban roundabouts in the Greek road network. The results of this study are useful for understanding how quality factors affect the driver’s perception of the roundabout. However, further studies based on big data are necessary in order to test the model and better understand the influence of human factors (i.e., age, driving experience, attention level, and eye-glance perception) and local conditions on driving behavior. Additionally, a combined model that would include the perception of pedestrians and cyclists could present a more integrated explanatory approach.

The findings of this research could be useful to transportation engineers and policymakers, including during the design stage or maintenance, or while deciding on the construction of a new roundabout.
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