

DETERMINATION OF PHARMACY TRANSPORTATION QUALITY INDEX BASED ON A FUZZY APPROACH: A CASE STUDY IN ANTALYA

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Highlights:

- a hierarchical FIS process for measuring the quality of accessibility to pharmacies is proposed for the 1st time;
- PTI based on fuzzy approach is appraised;
- PTI gains importance during a pandemic such as COVID-19 outbreak;
- disability conditions, transportation and location features are included as input;
- decision-makers can use the results for urban planning and engineering.

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Abstract. Quality is one of the most essential and comprehensive attributes of a transportation system's performance. High-quality, comfortable, safe, and disability-responsive transportation for Healthcare Facilities (HFs), pharmacies especially in this article, are vital in urban areas. This study aims to measure Pharmacy Transport Index (PTI) containing many complex parameters, in a practical, effective, easy-to-understand and fast way within the framework of the logic perspective that reflects human reasoning provided by the fuzzy approach. The fuzzy approach comprises 4 sub- and one-main Mamdani-type Fuzzy Inference System (FIS). Subsystems are: Comfort (1st), Safety (2nd), Security (3rd), and Disabled condition (4th). While the 1st FIS includes 4 inputs: Road type, Parking spaces, Entrance, and Rest areas, the 2nd FIS contains 3 inputs, which are: Bus stop, Pedestrian crossing, and Signalized intersection. Simultaneously, the 3rd FIS encompasses 2 inputs, which are: Entry door width and Street lamps; the 4th FIS has 6 inputs, which are including: Disabled parking spaces, Entrance ramps, Entrance steps, Entry door type, Sidewalk ramps, and Tactile paving. The PTI is obtained by combining the outputs of these subsystems in a final FIS. The system is implemented according to the data of 492 pharmacies in the city centre of Antalya (Turkey). These used data were revealed by visiting the locations of all pharmacies one by one. Results demonstrate that some pharmacies have good transportation quality, while others require progress on safety and security dimensions. Therefore, it can be observed that the proposed practical system contributes to providing an important insight into decision-making for transportation policy and environment. This system can also be easily integrated into other critical places such as schools, hospitals, police stations, etc., in the cities.

Keywords: transportation, pharmacy, fuzzy, disability, quality.

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Notations

- | | |
|--|---|
| AHP – analytic hierarchy process; | HFU – healthcare facility user; |
| API – application programming interface; | LoM – largest of maxima; |
| BoA – bisector of area; | MCDM – multiple-criteria decision-making; |
| CoA – center of area or centroid; | MoM – mean of maxima; |
| E2SFCA – enhanced 2-step floating catchment area | PROMETH- preference ranking organization method for |
| FIS – fuzzy inference system; | EE – enrichment of evaluations; |
| GIS – geographic information system; | PTI – pharmacy transportation index; |
| GRA – grey relational analysis; | SoM – small of maxima; |
| HF – healthcare facility; | TOPSIS – technique for order of preference by similarity to ideal solution. |

1. Introduction

Transportation is an integral part of the social, industrial, and economic process faced with increasing demand and development in vehicles leading to a deterioration of transportation infrastructure in metropolitan cities. Particularly, since transportation to critical places or institutions is essential, environmental regulations of such places are expected to be made according to certain conditions or parameters for better quality transportation. Places that provide health services are among the most critical of these. Transportation is a fundamental and necessary step for ongoing health care and medication access. There is increasing interest in the impact of transportation decisions on public health. Moreover, access to health services and pharmacies for potential HFUs becomes more critical during chronic disease periods (e.g., hypertension, diabetes, osteoporosis) and epidemics such as COVID-19. Pharmacies, one of the institutions that provide health services, are vital HFUs that people mostly use and are responsible for the safe, effective use, sale, and control of medications, medical equipment, and drugs. Often, when needed, the patient's 1st point of contact is the pharmacist, even before consulting a physician. In addition, most people who need medication frequently, even monthly, have chronic illnesses. Consequently, these people go to a pharmacy more often than they want advice from any other health-care professional. However, when we reviewed the literature for these critical issues, we could not find a novel measurement system including uncertainty and incoherent information for accessibility evaluation to pharmacies. Thus, the following question may come to mind:

- “can an accessibility assessment system be created for HFUs that can be used in daily life, which is practical, easily understandable, and considers ambiguous information?”.

To answer this research question, we propose the pharmacy transportation quality index (PTI) by constructing a set of FISs in this article. In other words, we introduce a collective system defining pharmacy accessibility quality by a FIS index named PTI. The proposed system contains 15 parameters under 4 main dimensions: Comfort, Safety, Security, Disabled condition. In order to evaluate these complex, dissimilar, and unrelated factors together in a model and at the same time to ensure that it has a practical, fast-resulting, easily understandable-updatable and effective structure, Mamdani-type fuzzy logic inference structure has been handled. Contrary to the structural equation models, surveys or empirical studies, the use of the fuzzy inference approach has stood out as it is a system that can be continuously updated and integrated into different cities, regions and various critical institutions. The data from 492 pharmacies in Antalya city centre is collected for the study. This study contributes to the literature on pharmacy transportation from different aspects. These contributions are highlighted as follows:

- this study is the 1st research on pharmacies' accessibility quality in a large city, including many factors. Quality of

accessibility to pharmacies is important because potential HFUs are prone to select “the easiest access”. Therefore, the location attributes of the HF, such as the pharmacy, are key to understanding a pharmacy's accessibility quality. At this point, PTI will suggest an insight into accessibility in terms of transportation parameters;

- to the best of our knowledge, FIS has not been used for measuring the quality of accessibility to HFUs. Therefore, a new approach is proposed in this study;
- moreover, one of the essential inputs of the proposed system is the disability conditions. Since several HFUs are disabled or disabled people with companions, PTI indicating pharmacies' accessibility quality should be well defined. High accessibility quality may provide a valid reason for preferring HF;
- PTI is critical for the periods such as pandemic periods (e.g., the COVID-19 outbreak since 2019). The pandemic and lockdowns (full or partial lockdown) showed that access to HFUs such as pharmacies was crucial. People in emergency sought an HF such as an accessible pharmacy. In this manner, PTI has gained considerable value during the pandemic.

The article is organized as follows:

- current Section 1 – an introduction;
- in the Section 2, a literature review of the concept is provided;
- Section 3 explains the structure of the fuzzy logic inference system;
- the related factors influencing the PTI index are discussed in Section 4;
- the proposed system and experimental results are presented in Section 5;
- in Section 6, the discussion and conclusion are given;
- Appendix section includes detailed information is displayed.

2. Literature review

Fuzzy logic is a mathematical approach to modelling many processes characterized by subjectivity, ambiguity, and imprecision. Fuzzy logic systems contribute to decision-making in complex problems by blending imprecise information and observations. As a result, fuzzy systems have many beneficial applications in transportation and traffic engineering, planning, and control. Teodorović (1999), Hoogendoorn *et al.* (1999), Chattaraj & Panda (2010), Sarkar *et al.* (2012), Duong & Ammarapala (2013) presented a review, outlook and analysis of the results achieved using fuzzy logic to model complex traffic and transportation problems and processes. The studies concern fuzzy logic systems for transportation engineering, including fuzzy transportation planning models, trip generation and distribution, transportation decision and investment projects, transportation maintenance and rehabilitation, traffic flow and control models, vehicle routing and scheduling, accident analysis and prevention, level of service considerations, air transportation, and river transportation applications, and so forth.

There are remarkable studies including fuzzy logic and transportation in literature. For example, fuzzy logic was applied to evaluate a transportation network in a specific region using the AHP and various optimization techniques (Hsu 1999; Lau *et al.* 2009; Zhou *et al.* 2013). Smith (2012) and Das *et al.* (2020) used intuitionistic fuzzy sets to assess highway networks, and upgrade their capacity, and serviceability. Later they searched for transport-related environmental issues. A couple of studies introduced fuzzy logic approaches such as integrated type-2 fuzzy TOPSIS and GRA method to evaluate public transportation systems in large cities or towns (Karsak, Ahiska 2005; Celik *et al.* 2013; Fornalchik *et al.* 2015). Ojha *et al.* (2011) investigated single and multi-objective transportation model formulations with fuzzy relations under fuzzy logic. Moreover, Kabir & Sumi (2014) used fuzzy AHP to decide facility locations in a transportation network by including the preference ranking organization method to enrich evaluations (PROMETHEE). On the other hand, Basiri & Malek (2014) examined how accessible ambient services are according to a user's location by using the fuzzy logic model, including 4 inputs. Additionally, Davtalab & Alesheikh (2019) offered a model to provide valid transportation ways for specific service requests by using a fuzzy approach to decrease spatial linguistic phrases' uncertainty. However, determining the transportation index for manufactured products using fuzzy logic is uncommon. One recent study proposed a model for investigating transportation sustainability performance depending on fuzzy logic in dairy industry (Djekic *et al.* 2018). They offered a dairy transportation sustainability index of multiple-criteria: resource depletion, climate impact, economy, and society. Although they proved that their model is capable of indicating the transportation sustainability, the number of indicators they input would be increased because accessibility quality of facilities would affect the travel preferences and the final destination. Milutinović *et al.* (2020) presented an approach using data envelopment analysis and fuzzy logic for public postal network reorganization to minimize financial and social negative effects. An ANFIS model was provided by Božanić *et al.* (2021) in selecting a loader and MCDM methods were used for gathering data. Kuzmanović & Vukić (2021) proposed a new approach to identify travellers' preferences by conducting research on the attributes (i.e., related factors) of travel destinations. Their study takes a survey from a group of responders into account for assessing the predetermined related factors, however their methodology does not consider the environmental aspects of the travel destinations. Moreover, many other studies have also used the fuzzy approach (Torğul *et al.* 2022; Bhattacharya *et al.* 2022).

Pharmacies are essential in the community as primary sources of pharmaceutical services. They are the providers of various services, including supplying medicines within the law and providing vaccinations. In critical times and situations, pharmacy transportation becomes more important and is affected by several factors. In the literature,

there are some studies including both the pharmaceutical industry and transportation. Most of them are about the pharmaceutical data and logistics distribution sector (Repolho *et al.* 2019; Elrahman, Alluhaidan 2021). However, the studies including both fuzzy systems and pharmacy-related transportation issues are few in the literature. They are about either processing healthcare-related information using fuzzy-based technologies or examining particular diseases. For example, Zadeh *et al.* (2017) studied a model indicating pharmaceutical alternatives using specific criteria. They used pharmacy repository data as input, where they utilized fuzzy-based linguistic processing. As a result, they suggest a methodology refining drug categories better than previous conventional methods. Fathollahi-Fard *et al.* (2020) proposed a bi-objective optimization model for a multi-period and multi-depot home healthcare routing and scheduling problem in a fuzzy environment. Choudhury *et al.* (2021) consider a decision-making problem by using fuzzy logic on importing a particular medicine from a foreign country where there are several alternatives for choosing the country from which the medicine can be imported. Law *et al.* (2013) studied geographic access to community pharmacies in the province of Nova Scotia in Canada. Vilcea & Avram (2019) represented a social and geographical analysis of the spatial distribution of pharmacies using GIS methods for the evolution of the pharmacies' number, location, density, and accessibility to the population of Craiova city. Syed *et al.* (2013) summarized the empirical evidence on transportation barriers to health care access for primary and chronic disease care. In this review article, 61 studies were evaluated. The article indicates that transportation barriers are essential to healthcare access, particularly for those with lower incomes or the under/uninsured. Vidhya & Shanmugalakshmi (2020) assessed healthcare-related big data including types of diseases, clinics, laboratories, and pharmacies to analyse the multiple disease conditions using a modified AMFIS (M-ANFIS). Oglu *et al.* (2021) proposed a technique for forecasting pharmaceutical product demand and distribution at a pharmacy network applying fuzzy logic theory. However, our aims were not covered by those studies. Thus, the purpose of this study is to introduce a novel approach.

3. About fuzzy logic

Fuzzy logic provides artificial intelligence methods that resemble human reasoning for handling the various types of uncertainties. FISs produce output by processing incomplete, ambiguous fuzzy inputs of a problem that linguistic parameters can define. A FIS consists of a fuzzification interface, which transforms the crisp inputs into degrees of the match with linguistic values; a rule base containing a number of fuzzy IF-THEN rules; a database defining the membership functions of the fuzzy sets used in the fuzzy rules; a decision-making unit performing the inference operations on the rules; and finally, a defuzzification

tion interface, which transforms the fuzzy results of the inference into a crisp output (Figure 1). More information about this concept can be found in the literature (Mamdani, Assilian 1975; Zimmermann 1996; Sivanandam *et al.* 2007; Ross 2010).

A fuzzy set A in a universe of discourse X is defined by a membership function:

$$\mu_{\tilde{A}} : X \rightarrow [0, 1],$$

such that it associates a real number giving a membership degree of each element x in the range $[0, 1]$. Fuzzy numbers are special fuzzy sets satisfying the following conditions (Figure 2):

- convex fuzzy set (if $\mu_{\tilde{A}}(\lambda \cdot x_1 + (1-\lambda) \cdot x_2) \geq \min(\mu_{\tilde{A}}(x_1), \mu_{\tilde{A}}(x_2))$ for all $\lambda \in (0, 1]$ and $x_1, x_2 \in X$, then $\tilde{A}$ convex fuzzy set);
- normalized fuzzy set (if $\text{Core}(\tilde{A}) = \{x \in X : \mu_{\tilde{A}}(x) = 1\} \neq \emptyset$, then $\tilde{A}$ is normalized);
- its membership function is piecewise continuous;
- it is defined in the real number.

Different classes of fuzzy numbers such as: Triangular, Trapezoidal, Gaussian, S-shaped, G-bell, Z-shaped, and Sigmoidal fuzzy numbers appear in real-world problems. Therefore, fuzzy numbers are used in the fuzzification interface of an inference system; namely, inputs are described by fuzzy numbers in the system. A fuzzy rule base consists of a set of fuzzy IF–THEN rules, which are the main theme of the FIS. All other components such as membership functions are used to implement these rules in a reasonable, realistic, and efficient manner. A fuzzy IF–THEN rule generally assumes the form:

$$R: \text{IF } x_1 \text{ is } \tilde{A}_1 \text{ AND (OR) } x_2 \text{ is } \tilde{A}_2, \text{ THEN } y \text{ is } \tilde{B}, \quad (1)$$

where: $\tilde{A}_1, \tilde{A}_2, \tilde{B}$ are linguistic variables of the FIS defined by fuzzy numbers on input and output universes, respectively. Logical operators AND, OR are known as the fuzzy intersection or conjunction (AND), and fuzzy union or disjunction (OR), respectively are defined as follows:

$$\begin{aligned} \tilde{A}_1 \text{ AND } \tilde{A}_2 &: \min(\mu_{\tilde{A}_1}, \mu_{\tilde{A}_2}); \\ \tilde{A}_1 \text{ OR } \tilde{A}_2 &: \max(\mu_{\tilde{A}_1}, \mu_{\tilde{A}_2}). \end{aligned} \quad (2)$$

After determining the rule base, we apply the process by which the fuzzy sets that represent the outputs of each rule are combined into a single fuzzy number (set), which is known as the aggregation of rules. Different operators such as Max, Sum or probabilistic OR could be used for aggregation. The Max operator is generally preferred when compensation between input variables is desirable. The Max operator is given by:

$$\mu_{\text{output}} = \max(\mu_{\text{rule}^1}, \mu_{\text{rule}^2}, \dots, \mu_{\text{rule}^r}). \quad (3)$$

The last step is the defuzzification interface such that the output fuzzy set obtained after the aggregation step is changed to a crisp number. Defuzzification techniques used in Mamdani-type FIS are generally CoA, BoA, SoM,

MoM, and LoM. For example, the BoA (Figure 3) gives a defuzzified crisp value x^* corresponding to a vertical line that divides the region under the curve into 2 sub-regions of equal area.

$$\mu_{\tilde{A}}(x) = \begin{cases} 0, & x < a_1; \\ \frac{x - a_1}{a_2 - a_1}, & a_1 \leq x \leq a_2; \\ 1, & a_2 \leq x \leq a_3; \\ \frac{a_4 - x}{a_4 - a_3}, & a_3 \leq x \leq a_4; \\ 0, & x > a_4. \end{cases} \quad (4)$$

All these mathematical operations explained above can be done using the MATLAB Fuzzy Logic Toolbox (<https://se.mathworks.com/products/fuzzy-logic.html>). In this article, Mamdani-type FIS is used for the PTI. We apply the max–min inference method for composition and minimum operator for implication. Triangular (Trimf) or Trapezoidal (Trapmf) fuzzy numbers whose membership function is defined in Equation (4) are used generally for the inputs and outputs. Trapezoidal fuzzy numbers given in Figure 4 are modelled by $\tilde{A} = [a_1 \ a_2 \ a_3 \ a_4]$ and triangular fuzzy numbers are defined as $\tilde{A} = [a_1 \ a_2 \ a_3]$, where $a_2 = a_3$.

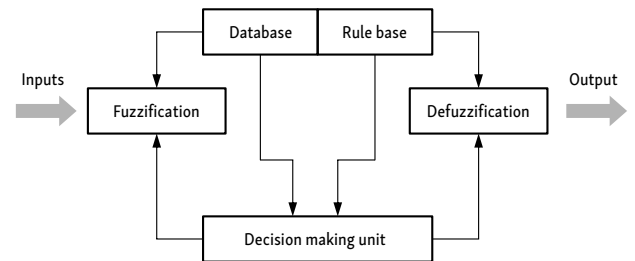


Figure 1. FIS

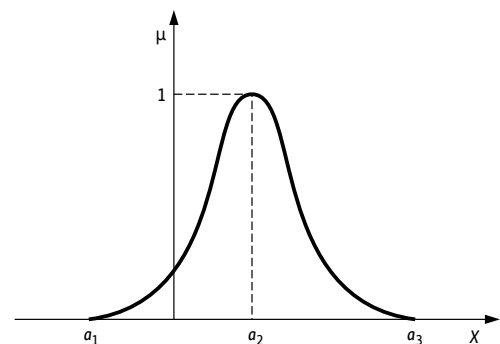


Figure 2. Fuzzy number

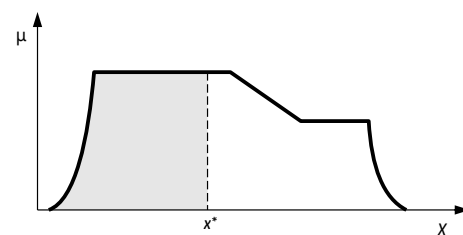


Figure 3. BoA defuzzification

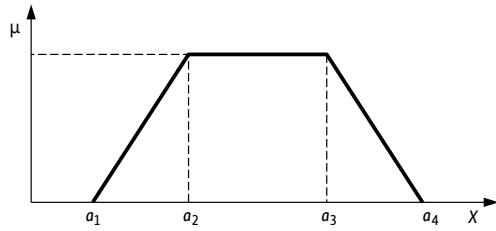


Figure 4. Trapezoidal fuzzy number

The aggregation is determined as the Max operator. As the defuzzification method, the BoA is chosen for the proposed Mamdani-type FISs discussed below.

4. Related factors

Various factors are affecting the quality of transportation for critical places in public. However, the fuzzy model proposed in this study is underpinned by 4 central sub-FISs such as Comfort, Safety, Security, and Disabled condition. Moreover, the model consists of fifteen factors related to the sub-FISs given in Figure 5. These factors are determined in the light of the literature review and their importance and necessities are examined in detail below.

4.1. Comfort

Transportation comfort is crucial in appraising accessibility quality (Elbanhawi *et al.* 2015; Kisgyörgy, Tóth 2020). Therefore, an overall analysis of comfort conditions is necessary to determine the pharmacies' accessibility quality from an origin to a pharmacy as the destination. In the proposed model, the comfort criterion is evaluated by

4 sub-factors: road type, parking spaces, entrances, and rest areas.

4.1.1. Road type

The significance of comfortable access to a facility is always critical for reaching a service. Furthermore, it has been increased, especially during the COVID-19 pandemic. For arriving at a destination, for example, a specific facility, the road type such as street, avenue, and boulevard in urban areas presents a path option for reaching the service. Moreover, although the road type varies in terms of traffic flow level, traffic density, and topology, it provides the comfort of driving depending on the traffic amount and the number of crashes (Cameron, Elvik 2010; Matisziw, Demir 2016). Thus, pharmacy's accessibility quality must contain the road type factor.

4.1.2. Parking spaces

As a commuter would visit a facility in urban areas, one of the critical considerations is the number of available parking spaces belonging to the facility. Furthermore, especially if private transportation is preferable, such as in the COVID-19 pandemic, parking spaces are vital for individual road users. This cause is a kind of attraction for the customers, and it affects the trip destination to access a particular service. Thus, the number of parking spaces helps select the destination store or facility to access the service comfortably. In other words, the trip production and attraction depend upon the available parking spaces at the destination (Tam, Lam 2000; Correia, Van Arem 2016). Therefore, the number of parking spaces is included as a sub-factor of comfort criterion in this study.

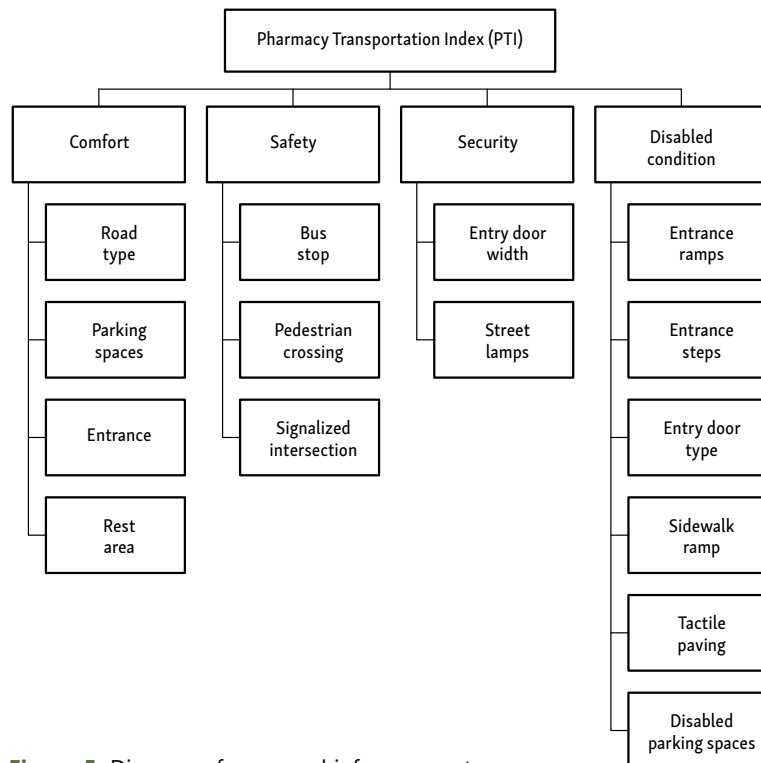


Figure 5. Diagram of proposed inference system

4.1.3. Entrances

As the urban areas are crowded regions, the service demanded from the facilities may increase during an event or emergency such as a pandemic. Facilities such as pharmacies may be overpopulated during extraordinary times, as many people experienced in the last few years due to the COVID-19 pandemic. In this case, pharmacy's the number of entrances can make the difference to provide accessibility comfort for the patients or customers, affecting PTI. Since COVID-19 is contagious, increasing the number of entries that are the exit simultaneously offers a comfortable admission by keeping the social distancing from the other pharmacy visitors.

4.1.4. Rest areas

Rest areas are essential during a trip, especially for increasing the comfort of the travel. Additionally, the number of rest areas for relaxing affects the preference of the destination location. For example, the number of seating benches in a shopping mall is an attraction for the visitors (Miller 2014; Das, Varshneya 2017). Figure 6 shows a seating bench close to a pharmacy as a rest area. For the model, the number of rest areas within a 50 m around the pharmacy is included. Therefore, the number of rest areas is a crucial sub-factor in modelling PTI.

4.2. Safety

In this research, the authors check many safety factors influencing the pharmacy's accessibility quality and thus PTI. However, 3 significant sub-factors are examined in this article. The incentive behind entering them into the model is discussed in the following.

4.2.1. Bus stops

Bus stops are relatively safe areas, and thus public transit users travel in substantially safe conditions (Ye *et al.* 2016; Cheranchery *et al.* 2019). Therefore, bus stops close to the pharmacy increase the level of secure access to the pharmacy. In light of this, the proposed model consists of the number of bus stops 50 m around the pharmacy, which may significantly impact PTI from the perspective of pharmacy visitors.

4.2.2. Pedestrian crossings

Pedestrian crossings are one of the significant safety measures for pedestrians in urban areas. They are essential to provide a safe walking path between 2 sides of the roadway because pedestrians are the most vulnerable and defenceless road users to traffic crashes (Boarnet *et al.* 2005; Guo *et al.* 2012; Pour-Rouholamin, Zhou 2016). The proposed model includes the number of pedestrian crossings 50 m around the pharmacy because a pedestrian crossing, such as in Figure 7, offers safe accessibility for pharmacy visitors, is a vital safety feature for walking commuters, and has great potential to change the PTI.

4.2.3. Signalized intersection

Several investigations demonstrate that the signalized intersection decreases the number of crashes on urban roads. Accordingly, the safety level of road users is increased by building signalized intersections in the cities (Miranda-Moreno *et al.* 2011; Huang *et al.* 2017). Further, the importance of the pedestrian safety index in urban roads increases (Marisamynathan, Vedagiri 2018). Therefore, the number of signalized intersections around the pharmacy is critical to enhancing the safety of the pharmacy visitors, and it is embedded in the proposed model as a sub-factor.

4.3. Security

Apart from comfort and safety factors, some other components, including security issues, have also arisen, which have a high potential to affect PTI. One of them is the security effect, which is evaluated with 2 sub-factors discussed in the following.

4.3.1. Entry door width

The structural and architectural design of a facility building is established on several design criteria. One of the crucial criteria that designers try to provide is the sense or feeling of security (Illera *et al.* 2010). Entry door width can help acquire a secure design because it supports a cognitive awareness of the escape route in an emergency. Therefore, the entry door width sub-factor is essential to be included in the model.

4.3.2. Street lamps

Many research support that it is essential to guarantee a sense of security with lighting at night (Kitsinelis, Zissis 2012; Kobayashi, Kakudate 2016). Besides many trips to the pharmacy are made after dark, the feeling of security on the way is essential. Therefore, the number of street lamps around the pharmacy is considered as a sub-factor in the study. As depicted in Figure 8, the street lamps in the 50 m vicinity of pharmacies are counted and used as input.

4.4. Disabled condition

3 main related factors are discussed so far for this study. Lastly, the factor of Disabled conditions is considered. Since disabled people are often considered transportation disadvantaged individuals, transportation features to facilities are pretty important for them. In addition, they generally face limitations that keep them out of the community (Casas 2007; Mackett, Thoreau 2015; Bascom, Christensen 2017). Therefore, the pharmacy's accessibility quality and thus PTI is thought to be influenced by several factors depending on transportation features that disabled people can use. The motivation behind introducing them into the proposed model is discussed in the following.



Figure 6. Rest area close to a pharmacy in Antalya
(<https://www.google.com/maps/@36.8889295,30.6243906,3a,75y,113.21h,88.85t/data=!3m6!1e1!3m4!1snmqZpcV4pcuh5kLjikUfg!2e0!7i16384!8i8192>)



Figure 7. Pedestrian crossing close to a pharmacy in Antalya
(<https://www.google.com/maps/@36.8574573,30.7705746,3a,75y,346.73h,64.23t/data=!3m6!1e1!3m4!1s6dthOW7ODNmFoELsZMuzHA!2e0!7i16384!8i8192>)



Figure 8. Street lamps in front of a pharmacy in Antalya
(<https://www.google.com/maps/@36.8539455,30.6190361,3a,75y,82.53h,108.29t/data=!3m6!1e1!3m4!1sp8twpfgVRqDfy1aABUmig!2e0!7i16384!8i8192>)

4.4.1. Disabled parking spaces

In the last few decades, many people with disabilities use private vehicles for transportation. Therefore, they need disabled parking spaces, essential structures for their mobility (Bascom, Christensen 2017; Lu *et al.* 2019). Because parking nearby a facility such as a pharmacy is crucial for people with fewer mobility abilities, the number of disabled parking spaces is included as a sub-factor in the model proposed. Figure 9 depicts a free parking space reserved for private vehicles that disabled people use.

4.4.2. Entrance ramps

In the perspective of physically disabled users, entrance ramps play a critical role in the accessibility status of facility buildings (Mojtahedi *et al.* 2008; Bodaghi, Zainab 2013). Ramps make access easy, especially for those with limited walking abilities, such as wheelchair users (Figure 10 and Figure 11). Therefore, in this study, the existence of the ramps at the pharmacy entrances is included as a sub-factor.

4.4.3. Entrance steps

There is a strong relationship between increased physical activity and stair use (Nicol 2007). However, this may not be the case for disabled people accessing a facility to get services such as a visiting pharmacy (Figure 11). Raised doorsteps should be avoided to reduce the access burden of physically disabled people (Irvall, Nielsen 2005). Thus, disabled people tend to choose entrances without stairs. Therefore, the entrance steps sub-factor can have an impact on PTI.

4.4.4. Entry door type

Infrastructural issues often limit physical access to facilities such as pharmacies. One of the most critical access criteria for people with physical disabilities is the facility's type of entrance door. In other words, using either the gates with manual openers or the doors with automatic systems for the visitors is crucial for comfortable access. Additionally, entrance doors should have a system of automatic openers for people with disabilities, according to Irvall & Nielsen (2005). Therefore, the entry door type is a sub-factor in the model proposed.

4.4.5. Sidewalk ramps

People with mobility disabilities have multiple barriers to transportation in urban areas. In this manner, sidewalk ramps are essential infrastructures to promote mobility for disabled people (Vredenburg *et al.* 2009; Rosenberg *et al.* 2013). Figure 12 demonstrates a sidewalk ramp in the vicinity of a pharmacy, which creates easy access to the particular pharmacy, especially for adults with physical disabilities such as wheeled mobility device users. Therefore, the number of sidewalk ramps nearby the pharmacy is involved in modelling PTI.



Figure 9. Disabled parking spaces close to a pharmacy in Antalya (<https://www.google.com/maps/@36.871148,30.6333886,3a,75y,49.19h,85.47t/data=!3m6!1e1!3m4!1sQcZmVseV0tOANA7DfCtfQ!2e0!7i16384!8i8192>)



Figure 10. Entrance ramp for a pharmacy in Antalya (<https://www.google.com/maps/@36.8742525,30.6264924,3a,75y,97.87h,86.42t/data=!3m6!1e1!3m4!1sSJldvuOML2tYe7UIFkqKqA!2e0!7i16384!8i8192>)

4.4.6. Tactile paving

Many people have completely lost his sight. There are embossed surfaces laid on the floor, for instance, tactile paving, to enable visually impaired individuals to move more effortlessly in outdoor areas. The blind commonly desires to track paths accompanied by assistive infrastructures such as walls or other guiding features such as tactile paving (Fernandes *et al.* 2019; Aktaş *et al.* 2020). Therefore, tactile paving near the pharmacy is significant for visually impaired individuals who would visit the pharmacy (Figure 12).

5. Proposed FIS

Mollon (2021), in his PhD thesis, investigated extensively conceptual models of pharmacy access, including various factors grouped as pharmacy landscape variables, population variables and community variables, in selected racially diverse urban areas of the US by applying GIS software mapping, the E2SFCA methodology, and multiple discriminant analysis in order to determine pharmacy access levels



Figure 11. Entrance steps and ramps in front of a pharmacy in Antalya (https://www.google.com/maps/@36.914634,30.6912071,3a,75y,310.73h,89.09t/data=!3m6!1e1!3m4!1s2gGvQ_Mk2S4CCNCs2RXzPg!2e0!7i13312!8i6656)



Figure 12. Tactile paving and sidewalk ramp in Antalya (<https://www.google.com/maps/@36.8588256,30.7922636,3a,75y,301.24h,74.45t/data=!3m6!1e1!3m4!1shYcV6ERkDBxi2UHlojzoYw!2e0!7i13312!8i6656>)

and scores. In detail, influential factors are considered as spatial accessibility of the pharmacy landscape: distance to the nearest pharmacy, travel time to the nearest pharmacy, pharmacy-to-population ratio; and spatial accessibility: population and community level variables classified as Culture, Social class, Socioeconomic position, Race/Ethnicity, Vulnerability, Residential stability and Transportation (e.g., Walk score, Worker commute by Car/Bike/Walking/Public, Households without a vehicle). The PhD thesis has an extensive literature review and says that limited research exists on pharmacy access areas and what factors contribute to decreased pharmacy accessibility and community pharmacies have often been overlooked in discussions on access to care. The author of the PhD thesis gathered and used related data obtained from some data sources, telephone screening, and online sources such as Google API (<https://cloud.google.com/apis>). On the other hand, modelling the impact of transportation on public health by means of the development process of FIS within the ArcGIS platform (<https://www.arcgis.com>) using the Sugeno method was investigated by Adhikari (2013) in his MSc thesis. This MSc thesis says that transportation plan-

ning, a major component of urban planning, can make both negative as well as positive impacts on the health of the general public based on a literature review. Only 3 factors, which are the commuting population, vulnerable population and population not doing physical activity, were used to study the incidence of obesity, considered as the health impact of transportation, in the Dallas – Fort – Worth Metroplex region. In this article, a different and novel approach is presented to the literature from the civil and transportation engineering perspective to determine the quality of pharmacy transportation/accessibility in a fuzzy environment. For this purpose, the recommended system consists of 4 sub-FISs and a final system given in Figure 5:

- the 1st FIS: Comfort;
- the 2nd FIS: Safety;
- the 3rd FIS: Security;
- the 4th FIS: Disabled condition;
- the Final FIS: PTI (pharmacy transportation quality index).

The 1st FIS including 4 variables provides an inference on Comfort of pharmacy accessibility, the 2nd FIS including 3 variables gives an output on Safety of pharmacy accessibility, the 3rd FIS including 2 variables represents a result about Security of pharmacy accessibility and finally the 4th FIS including 6 variables is formed for disability status of Pharmacy accessibility. After obtaining the outputs of these 4 sub-FISs, we get the pharmacy transportation index value by means of the Final FIS whose input values are the outputs of the sub-FISs.

In all these 4 sub-FISs and the Final FIS, the BoA is chosen as the defuzzification method. Moreover, the range of inputs are determined according to the collected data in all FISs. Additionally, we benefited from the expert knowledge and the data collected from 492 pharmacies in Antalya city centre while determining the parameter values of all factors/inputs of the following FISs. The data is obtained by visiting each pharmacy in Antalya city and considering

a circular area with a radius of 50 m that accepts the pharmacy as the centre (Appendix A). Triangular (Trimf) and trapezoidal (Trapmf) fuzzy numbers corresponding to the linguistic variables describing the fuzzy levels of the input and output variables for the following FISs are identified with the help of the data obtained, and the fuzzy number type is determined for these data. A detailed description of this for each FIS is provided in the following sections.

5.1. The 1st FIS: Comfort

In this FIS, we aim to obtain a crisp output that measures the Comfort of pharmacy transportation. There are 4 inputs influencing the inference of the sub-fuzzy approach, which are: Road type, Parking spaces, Entrance and Rest areas (Figure 13). Table 1 explains the linguistic variables of inputs-output and the corresponding membership functions of the FIS. In total, 54 IF–THEN rules are formed by expert's opinion for the Comfort of PTI given in the Appendix B.

The fuzzy membership function determination phase is completed on the basis of data and expert opinions. For example, in the city of Antalya, there are generally 3 options for the Road type: street, avenue and boulevard when the pharmacy locations were examined. The street was rated as the best option (1) and the boulevard was rated as the unsuitable option (0) according to the traffic situation.

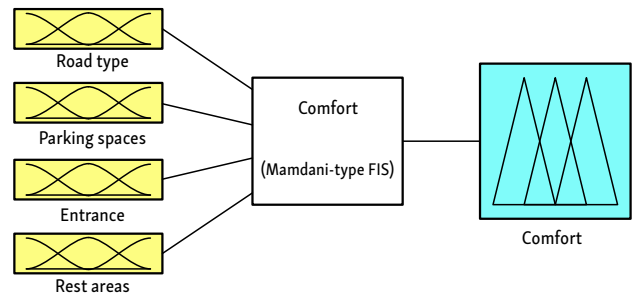


Figure 13. Inputs of the 1st FIS

Table 1. Fuzzy classification of input and output variables for Comfort

	Linguistic variable	Fuzzy membership function		
Input-1	Road type	Boulevard 0 [0 0 0]	Avenue 0.5 [0.5 0.5 0.5]	Street 1 [1 1 1]
Input-2	Parking spaces	Insufficient Trimf [0 0 5]	Moderate Trimf [0 5 10]	Sufficient Trapmf [5 15 100 100]
Input-3	Entrance	One entrance 1 [0 0 0]	– – –	2 entrances 2 [1 1 1]
Input-4	Rest areas	Insufficient Trimf [0 0 4]	Moderate Trimf [0 4 8]	Sufficient Trapmf [4 8 26 26]
Output	Comfort	Low Comfort Trimf [0 0 50]	Moderate comfort Trimf [20 50 80]	High comfort Trimf [50 100 100]

For the parking space variable, since the average number of parking spaces is 11 according to the data, when examined one by one, the limit values of the linguistic variables “insufficient” and “moderate” are determined as in Table 1 with the contribution of expert opinion, and Trapmf is used to indicate that the best value is 15 and above. Pharmacies with 2 entries are rated better in the system. Trapmf was used for the linguistic variable “sufficient”, as the pharmacies with 8 or more resting areas were determined best with expert opinion’s contribution and the maximum number was 26 according to the data collected.

5.2. The 2nd FIS: Safety

We aim to reach a crisp output assessing the Safety of pharmacy transportation in this FIS. 3 inputs affect the inference of the sub-fuzzy approach, which are: Bus stop, Pedestrian crossing, and Signalized intersection (Figure 14). In this manner, the information about the linguistic variables of inputs-output and the corresponding membership functions of the FIS are provided (Table 2). For this FIS, 8 IF–THEN rules totally are generated by the expert’s opinion for the Safety of PTI (Appendix B).

Similar to the 1st FIS, since the maximum number for the “Bus stop” variable is 4 and the average is taken into account, it was determined as the best grade for 3 and above and Trapmf was used for this. The “Pedestrian crossing” is similarly fuzzified in this perspective.

5.3. The 3rd FIS: Security

In this FIS, we focus on having a crisp output that measures the Security of pharmacy transportation. 2 inputs alter the inference of the sub-fuzzy approach: “Entry door width”, and “Street lamps” (Figure 15). Furthermore, Table 3 demonstrates the linguistic variables of inputs-output and the corresponding membership functions of the FIS. In the FIS for the Security of PTI, 9 IF–THEN rules are developed by experts’ opinion (Appendix B).

The maximum value for the input variable “Entrance door width” is 250 cm according to the data. Therefore, the moderate value is determined as 120 cm, and since the data average is approximately 100 cm, 200 cm or higher is fuzzified as “very wide”, which is why Trapmf is used in Table 3. For the input variable “Entrance door width”, the maximum value and the average are 10 and 4 approximately, so there is a similar approach for fuzzifying.

5.4. The 4th FIS: Disabled condition

With this FIS, we want to measure the Disabled condition of pharmacy transportation with a crisp output. The sub-fuzzy approach’s inference is influenced by 6 inputs: the presence of Disabled parking spaces, Entrance ramps, Entrance steps, Entry door type, Sidewalk ramps and Tactile paving (Figure 16). The linguistic input-output variables

and accompanying FIS membership functions are shown in Table 4. For the Disabled condition of PTI, 96 IF–THEN rules in total are established by expert judgment (Appendix B).

Like the previous FISs, in the fuzzification phase, the factors affecting the system were evaluated in terms of data and expert opinion, and they were tried to be determined appropriately. For instance, since the average number of “Disabled parking space” is very low and the maximum value is 32, values of 2 and above are described as “enough”. There are 2 options for “Entry door type” and “Tactile paving”. Similarly, it has been observed that the Trapmf membership function is more suitable for specifying limit values towards maximum values.

5.5. Pharmacy transportation quality index and experimental results

Now, we can obtain the pharmacy transportation quality index value providing an idea of the quality by combining the sub-FISs explained above. We present the final FIS whose inputs are the outputs obtained by the 1st, 2nd, 3rd and 4th sub-fuzzy approaches for the PTI (Figure 17). There are 81 IF–THEN rules given in Appendix B for the final FIS. Table 5 gives the structure of the linguistic variables, which are the outputs of the sub-FISs. Figure 18 and Figure 19 show the impact of the linguistic variables on PTI in 3D form as a rule surface performed in MATLAB on Security and Disabled condition, Safety and Comfort, respectively. These images give us an idea of how the parameters affect the system and verify that it is working properly.

Then, we can discuss the performance of the proposed fuzzy approach. According to the collected data given in Appendix A, we compute the PTI value between 0 and 100 by entering the outputs of the Comfort, Safety, Security and Disabled condition FISs into the final FIS specified above. For example, the data of 5 pharmacies chosen in Appendix A are presented in Table 6.

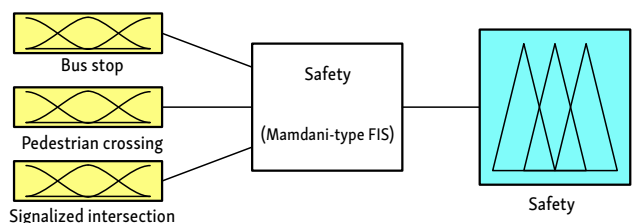


Figure 14. Inputs of the 2nd FIS

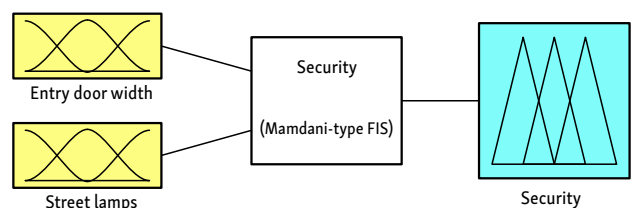


Figure 15. Inputs of the 3rd FIS

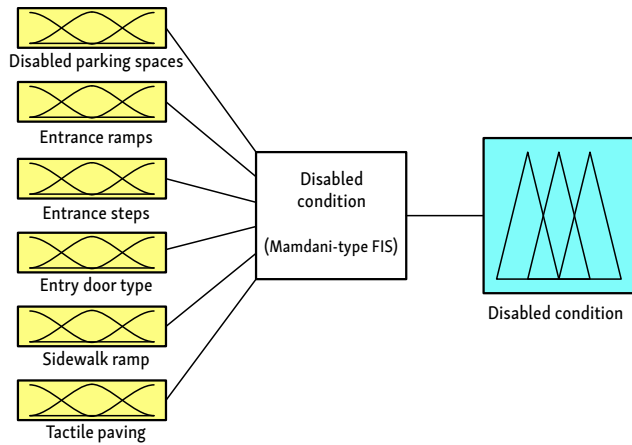


Figure 16. Inputs of the 4th FIS

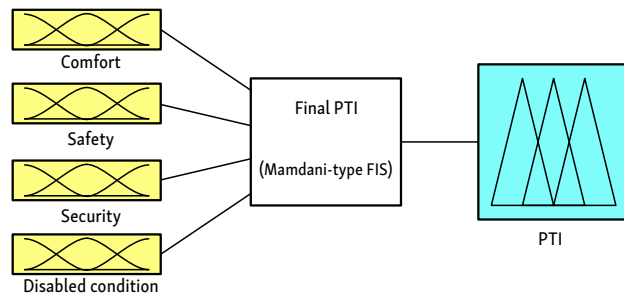


Figure 17. Inputs of the main FIS

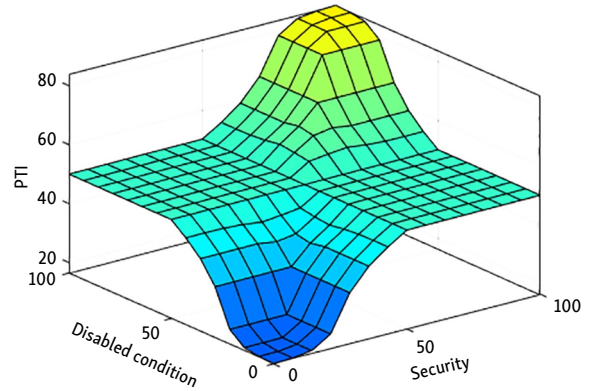


Figure 18. Surface view of the main FIS for Security and Disabled condition

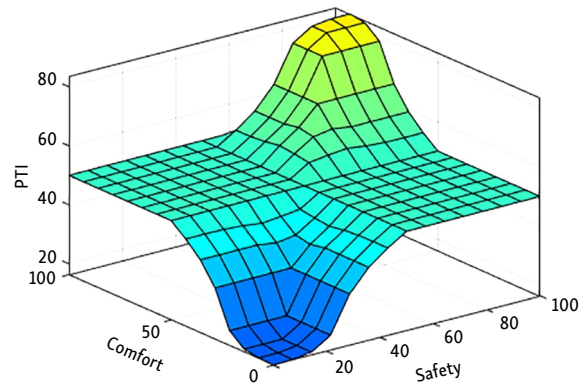


Figure 19. Surface view of the main FIS for Safety and Comfort

Table 2. Fuzzy classification of input and output variables for Safety

	Linguistic variable	Fuzzy membership function		
Input-1	Bus stop [0 4]	Little enough Trimf [0 0 3]	Enough Trapmf [0 3 4 4]	–
				–
				–
Input-2	Pedestrian crossing [0 5]	Little enough Trimf [0 0 4]	Enough Trapmf [0 4 5 5]	–
				–
				–
Input-3	Signalized intersection [0 1]	None 0 [0 0 0]	Available 1 [1 1 1]	–
				–
				–
Output	Safety [0 100]	Low safety Trimf [0 0 50]	Moderate safety Trimf [20 50 80]	High safety Trimf [50 100 100]

Table 3. Fuzzy classification of input and output variables for Security

	Linguistic variable	Fuzzy membership function		
Input-1	Entry door width [50 250]	Medium Trimf [50 50 120]	Wide Trimf [70 120 200]	Very wide Trapmf [120 200 250 250]
Input-2	Street lamps [0 10]	Insufficient Trimf [0 0 4]	Moderate Trimf [1 4 7]	Sufficient Trapmf [4 8 10 10]
Output	Security [0 100]	Low security Trimf [0 0 50]	Moderate security Trimf [20 50 80]	High security Trimf [50 100 100]

Table 4. Fuzzy classification of input and output variables for Disabled condition

	Linguistic variable	Fuzzy membership function		
Input-1	Disabled parking space [0 32]	Little enough Trimf [0 0 2]	Enough Trapmf [0 2 32 32]	– – –
Input-2	Entrance ramps [0 3]	Little enough Trimf [0 0 1.5]	Enough Trapmf [0 2 3 3]	– – –
Input-3	Entrance step [0 7]	Little Trimf [0 0 2]	Medium Trimf [1 3 5]	Many Trapmf [3 6 7 7]
Input-4	Entry door type [0 1]	Manual 0 [0 0 0]	Automatic 1 [1 1 1]	– – –
Input-5	Sidewalk ramp [0 7]	Little enough Trimf [0 0 3]	Enough Trapmf [0 4 7 7]	– – –
Input-6	Tactile paving [0 1]	No 0 [0 0 0]	Yes 1 [1 1 1]	– – –
Output	Disabled condition [0 100]	Poor Trimf [0 0 50]	Moderate Trimf [20 50 80]	Good Trimf [50 100 100]

Table 5. Fuzzy classification of input and output variables for the Main FIS

	Linguistic variable	Fuzzy membership function		
Input-1	Comfort [0 100]	Low Trimf [0 0 50]	Moderate Trimf [20 50 80]	High Trimf [50 100 100]
Input-2	Safety [0 100]	Low Trimf [0 0 50]	Moderate Trimf [20 50 80]	High Trimf [50 100 100]
Input-3	Security [0 100]	Low Trimf [0 0 50]	Moderate Trimf [20 50 80]	High Trimf [50 100 100]
Input-4	Disabled condition [0 100]	Poor Trimf [0 0 50]	Moderate Trimf [20 50 80]	Good Trimf [50 100 100]
Final output	PTI [0 100]	Poor Trimf [0 0 50]	Moderate Trimf [20 50 80]	Good Trimf [50 100 100]

Table 6. Data of 5 pharmacies

	Comfort				Safety			Security		Disabled condition					
	RT	PS	E	RA	BS	PC	SI	EDW	SL	DPS	ER	ES	EDT	SR	TP
Pharmacy-1	1	5	1	2	0	0	0	80	4	0	1	1	0	0	0
Pharmacy-2	0	45	1	15	2	0	0	150	5	0	1	1	1	0	0
Pharmacy-5	0	30	1	7	1	1	1	150	6	0	1	1	1	2	0
Pharmacy-489	0.5	100	2	10	2	2	1	150	5	0	0	0	1	3	1
Pharmacy-490	1	0	1	0	0	0	0	100	4	0	0	0	0	2	1

Notes: BS – Bus stop; DPS – Disabled parking spaces; E – Entrance; EDT – Entry door type; EDW – Entry door width; ER – Entrance ramps; ES – Entrance steps; PC – Pedestrian crossing; PS – Parking spaces; RA – Rest areas; RT – Road type; SI – Signalized intersection; SL – Street lamps; SR – Sidewalk ramps; TP – Tactile paving.

Table 7. PTI and sub-FIS results of the data given in Table 6

	C (1st FIS)	SA (2nd FIS)	SE (3rd FIS)	DC (4th FIS)	PTI (Final FIS)
Pharmacy-1	50	14	23	41	21
Pharmacy-2	85	14	43	18	48
Pharmacy-5	50	34	70	70	66
Pharmacy-489	86	55	58	85	84
Pharmacy-490	14	14	44	50	16

Notes: C – Comfort; DC – Disabled condition; SA – Safety; SE – Security.

The output values for the input data of Table 6 are presented in Table 7 and obtained with MATLAB Fuzzy Logic Designer (<https://se.mathworks.com/help/fuzzy/fuzzylogicdesigner-app.html>). The results show that Pharmacy-489 has significantly better PTI, which means that its transportation quality is excellent in Antalya city centre. Pharmacy-5 also has good PTI and should improve its safety index slightly. The Pharmacy-1 and pharmacy-490 need to be more competent and they should improve especially their safety and security indices. So, these comments can be more detailed and more profound. Since the PTI includes many parameters in the same system, it really helps and guides to increase the quality of transportation for pharmacies.

6. Discussion and conclusions

In this article, a set of FIS was proposed to get an idea very practically and quickly about the quality index of pharmacy transportation in Antalya, because no study has been seen that FIS is used to measure the quality of accessibility to HFs when we look at the literature. The data from 492 pharmacies were processed for the FISs formed in the study. The proposed approach had 4 sub-FISs: Comfort, Safety, Security, and Disabled condition. In the final FIS, the outputs of the sub-FISs were managed to determine the PTI.

Addressing the quality of accessibility to pharmacies is required because emergency patients seek an HF such as an accessible pharmacy, and the PTI reveals a pharmacy's transportation quality. PTI has gotten extraordinary value in pandemics such as the COVID-19 outbreak. The public discovered during lockdowns that access to HFs such as pharmacies was crucial. In this manner, this study researched pharmacies' transportation quality for the 1st time. Furthermore, location attributes of HFs are vital to understanding a pharmacy's accessibility quality because HFUs are susceptible to selecting the most accessible HFs. Therefore, determining the PTI procedure proposed in this article infers an insight into the interpretation of the pharmacy accessibility. On the other hand, the utilization of a comprehensive set of 15 parameters across 4 main dimensions demonstrates our technique's effectiveness across various aspects. Despite the inherent challenges associated with establishing a mathematical model incorporating such complex parameters, the practicality, simplicity, expediency, and successful outcomes observed

with the proposed approach contribute to addressing the complexities of the problem, highlighting its novelty and necessity.

This study also offered to include disability conditions as input for the 1st time to project PTI, since numerous HFUs are disabled or incapacitated. The results show that disability conditions increase the PTI considerably, proving pharmacies with high PTI are preferential and convenient for disabled HFUs. Studies on this subject continue to take place in recent times (Grisé *et al.* 2019; Mogaji, Nguyen 2021; Mohri *et al.* 2021).

Decision-makers such as urban planners, engineers, and pharmacists can use the resulting numerical data to make inferences about transportation quality. According to experts' opinions and new ideas, improvements and updates can be practically made on the rule base and input parametric values for different metropolitan cities. This study's mobile or digital application can easily be formed in digital platforms. In this study, we also considered bike parking spaces as an input for the Comfort sub-FIS, but the data of pharmacies in Antalya could have been more satisfying. However, this factor can be included in the research for other metropolitan cities.

This method can be applied to other critical public places such as schools, hospitals, kindergartens, police stations, military regions and so forth by determining proper inputs and linguistic variables. We can see some studies in the literature on improving transportation. For example, McDonald *et al.* (2016) present some results for the cost of school transportation. Rothman *et al.* (2018) provide a systematic review, which is an examination of active school transportation factors and changes. In addition, Kergosien *et al.* (2011) propose a method for the dynamic transportation of patients between care units. Moreover, this approach can also be customized for transportation between hospitals and pharmacies, which is essential for acute diseases and emergencies. Indeed, during the COVID-19 outbreak, we have seen the importance of transportation quality in urban areas. Additionally, Antalya is a major international tourism city that millions of tourists and travellers visit annually. The proposed application can be practical for such tourism regions, as well. Therefore, the importance of pharmacy transportation quality increases in this sense.

The limitation of this study is to assign the optimized linguistic variables and their corresponding membership functions for the parameters affecting the measurement

of the transportation quality. Therefore, experts' opinions, the related data, and the nature of fuzzy logic play an important role. Examining the approaches or methods that approximate the optimized values in the fuzzification step will further increase the efficiency and usefulness of the system. This can serve as recommendations for further research.

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Author contributions

Hakan Şimşek and *Emre Demir* conceived the study and were responsible for the design and development of the data analysis.

Emre Demir were responsible for data collection and analysis.

Hakan Şimşek were responsible for data interpretation.

Hakan Şimşek wrote the 1st draft of the article.

Hakan Şimşek and *Emre Demir* revised the article.

Disclosure statement

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this article.

Ethical approval or formal consent is not required for this article.

A portion of all data generated and analysed during this study are included in this article as Appendix A. All data are available from the corresponding author on reasonable request.

Declaration on the use of Artificial Intelligence (AI)

During the preparation of this manuscript, the authors did not use generative AI or AI-assisted technologies.

The authors take full responsibility for the content of this manuscript.

Appendix A. Pharmacy data in Antalya city center

	Comfort				Safety			Security		Disabled condition					
	RT	PS	E	RA	BS	PC	SI	EDW	SL	DPS	ER	ES	EDT	SR	TP
Pharmacy-1	1	5	1	2	0	0	0	80	4	0	1	1	0	0	0
Pharmacy-2	0	45	1	15	2	0	0	150	5	0	1	1	1	0	0
Pharmacy-3	1	6	1	10	0	0	0	90	5	0	1	4	0	0	0
Pharmacy-4	0	6	1	2	1	1	1	75	6	0	0	0	0	2	0
Pharmacy-5	0	30	1	7	1	1	1	150	6	0	1	1	1	2	0
Pharmacy-6	0.5	100	1	0	2	1	0	200	4	20	0	0	1	0	0
Pharmacy-7	1	0	2	0	1	0	0	75	3	0	1	6	0	0	0
Pharmacy-8	1	10	1	3	0	0	0	90	4	0	2	4	0	2	0
Pharmacy-9	1	0	1	0	0	0	0	75	2	0	0	0	0	2	0
Pharmacy-10	1	11	1	9	0	0	0	75	4	0	1	2	0	2	1
Pharmacy-11	0	0	2	2	1	2	1	100	4	0	1	1	1	2	1
Pharmacy-12	1	0	1	0	1	0	0	75	3	0	0	0	0	2	0
Pharmacy-13	0	100	1	0	4	1	1	250	10	10	0	0	1	0	0
Pharmacy-14	0.5	0	2	0	2	1	0	150	6	0	2	2	1	3	1
Pharmacy-15	0.5	0	1	1	2	1	0	100	6	0	0	1	1	2	1
Pharmacy-16	0	0	1	0	2	1	1	75	6	0	1	2	0	2	0
Pharmacy-17	1	0	1	0	0	0	0	90	3	0	1	0	0	2	0
Pharmacy-18	1	0	2	0	2	2	1	150	4	0	1	3	1	2	1
Pharmacy-19	0	0	1	0	2	2	1	200	5	0	1	1	0	3	1
Pharmacy-20	0	0	1	0	2	2	1	150	5	0	1	1	1	3	1
Pharmacy-21	0.5	0	1	0	2	1	0	80	6	0	0	0	0	0	1
Pharmacy-22	0.5	0	1	0	2	1	0	80	6	0	0	0	0	0	1
Pharmacy-23	0	0	1	0	2	1	0	80	5	0	0	1	0	3	1
Pharmacy-24	0.5	0	1	0	2	1	0	80	6	0	0	0	0	0	1
Pharmacy-25	0.5	0	2	0	2	1	0	150	6	0	3	3	1	0	1
Pharmacy-26	1	0	1	10	0	1	0	220	3	0	1	4	1	0	0
Pharmacy-27	1	0	1	10	0	1	0	90	3	0	1	3	0	0	0
Pharmacy-28	0.5	100	2	9	0	1	0	75	4	0	1	6	0	2	0
Pharmacy-29	0.5	0	1	7	2	1	1	80	6	0	0	0	0	3	1
Pharmacy-30	0.5	100	1	9	0	1	0	75	4	0	0	0	0	2	0
Pharmacy-31	0.5	0	1	0	2	1	1	75	7	0	1	1	0	2	0
Pharmacy-32	0.5	0	1	0	2	1	1	150	7	0	0	0	1	2	0
Pharmacy-33	0.5	0	2	0	2	1	1	75	7	0	0	0	0	2	0
Pharmacy-34	0	0	1	1	2	2	1	100	6	0	0	0	1	3	0
Pharmacy-35	0	0	1	1	2	2	1	90	6	0	0	0	1	3	0
Pharmacy-36	1	0	1	0	0	0	0	75	4	0	0	0	0	0	0
Pharmacy-37	0	0	2	0	2	2	0	100	8	0	1	4	1	4	1
Pharmacy-38	1	80	1	0	1	0	0	75	5	0	1	1	0	1	0
Pharmacy-39	1	20	1	15	2	1	0	150	4	0	0	1	1	2	0
⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮
Pharmacy-486	0	100	1	0	2	4	1	100	5	0	0	0	0	2	1
Pharmacy-487	0.5	0	1	0	2	2	1	100	8	0	0	0	0	3	1
Pharmacy-488	0.5	0	1	0	2	2	1	75	4	0	0	0	0	3	1
Pharmacy-489	0.5	100	2	10	2	2	1	150	5	0	0	0	1	3	1
Pharmacy-490	1	0	1	0	0	0	0	100	4	0	0	0	0	2	1
Pharmacy-491	0.5	0	1	5	2	2	1	90	4	0	0	0	0	3	1
Pharmacy-492	0.5	0	1	5	4	1	1	200	8	0	0	1	0	1	1
Min	–	0	–	0	0	0	–	50	0	0	0	0	–	0	–
Max	–	100	–	26	4	5	–	250	10	32	3	7	–	7	–
Average	–	11.68	–	2.11	0.98	0.88	–	96.7	4.5	0.14	0.41	1.17	–	1.8	–

Notes: C – Comfort; DC – Disabled condition; SA – Safety; SE – Security.

Appendix B. Fuzzy IF–THEN rules

IF-1, IF-2, IF-3 IF-4 and IF-5 below show the fuzzy IF–THEN rules of Comfort, Safety, Security, Disabled condition and Final PTI FISs, respectively.

IF-1	Road type	Parking spaces	Entrance	Rest areas	THEN	Comfort
R1	boulevard	insufficient	one entrance	insufficient		low
R2	boulevard	insufficient	one entrance	moderate		low
R3	boulevard	insufficient	one entrance	sufficient		low
R4	avenue	insufficient	one entrance	insufficient		low
R5	avenue	insufficient	one entrance	moderate		low
R6	avenue	insufficient	one entrance	sufficient		moderate
R7	street	insufficient	one entrance	insufficient		low
R8	street	insufficient	one entrance	moderate		moderate
R9	street	insufficient	one entrance	sufficient		moderate
R10	boulevard	moderate	one entrance	insufficient		low
R11	boulevard	moderate	one entrance	moderate		low
R12	boulevard	moderate	one entrance	sufficient		moderate
R13	avenue	moderate	one entrance	insufficient		low
R14	avenue	moderate	one entrance	moderate		moderate
R15	avenue	moderate	one entrance	sufficient		moderate
R16	street	moderate	one entrance	insufficient		moderate
R17	street	moderate	one entrance	moderate		moderate
R18	street	moderate	one entrance	sufficient		high
R19	boulevard	sufficient	one entrance	insufficient		low
R20	boulevard	sufficient	one entrance	moderate		moderate
R21	boulevard	sufficient	one entrance	sufficient		moderate
R22	avenue	sufficient	one entrance	insufficient		moderate
R23	avenue	sufficient	one entrance	moderate		moderate
R24	avenue	sufficient	one entrance	sufficient		high
R25	street	sufficient	one entrance	insufficient		moderate
R26	street	sufficient	one entrance	moderate		high
R27	street	sufficient	one entrance	sufficient		high
R28	boulevard	insufficient	2 entrances	insufficient		low
R29	boulevard	insufficient	2 entrances	moderate		low
R30	boulevard	insufficient	2 entrances	sufficient		moderate
R31	avenue	insufficient	2 entrances	insufficient		low
R32	avenue	insufficient	2 entrances	moderate		moderate
R33	avenue	insufficient	2 entrances	sufficient		moderate
R34	street	insufficient	2 entrances	insufficient		moderate
R35	street	insufficient	2 entrances	moderate		moderate
R36	street	insufficient	2 entrances	sufficient		high
R37	boulevard	moderate	2 entrances	insufficient		low
R38	boulevard	moderate	2 entrances	moderate		moderate
R39	boulevard	moderate	2 entrances	sufficient		moderate
R40	avenue	moderate	2 entrances	insufficient		moderate
R41	avenue	moderate	2 entrances	moderate		moderate
R42	avenue	moderate	2 entrances	sufficient		high
R43	street	moderate	2 entrances	insufficient		moderate
R44	street	moderate	2 entrances	moderate		high
R45	street	moderate	2 entrances	sufficient		high
R46	boulevard	sufficient	2 entrances	insufficient		moderate
R47	boulevard	sufficient	2 entrances	moderate		moderate
R48	boulevard	sufficient	2 entrances	sufficient		high
R49	avenue	sufficient	2 entrances	insufficient		moderate
R50	avenue	sufficient	2 entrances	moderate		high
R51	avenue	sufficient	2 entrances	sufficient		high
R52	street	sufficient	2 entrances	insufficient		high
R53	street	sufficient	2 entrances	moderate		high
R54	street	sufficient	2 entrances	sufficient		high

IF-2	Bus stop	Pedestrian crossing	Signalized intersection	THEN	Safety
R1	little enough	little enough	none		low
R2	little enough	little enough	available		low
R3	little enough	sufficient	none		low
R4	little enough	insufficient	available		moderate
R5	enough	little enough	none		low
R6	enough	little enough	available		moderate
R7	enough	insufficient	none		high
R8	enough	moderate	available		high

IF-3	Entry door width	Street lamps	THEN	Security
R1	medium	insufficient		low
R2	medium	moderate		low
R3	medium	sufficient		moderate
R4	wide	insufficient		low
R5	wide	moderate		moderate
R6	wide	sufficient		high
R7	very wide	insufficient		moderate
R8	very wide	moderate		high
R9	very wide	sufficient		high

IF-4	Disabled parking spaces	Entrance ramps	Entrance steps	Entry door type	Sidewalk ramps	Tactile paving	THEN	Disabled condition
R1	little enough	little enough	little	manual	little enough	no		poor
R2	little enough	little enough	little	manual	little enough	yes		moderate
R3	little enough	little enough	little	manual	enough	no		moderate
R4	little enough	little enough	little	manual	enough	yes		moderate
R5	little enough	little enough	little	automatic	little enough	no		moderate
R6	little enough	little enough	little	automatic	little enough	yes		moderate
R7	little enough	little enough	little	automatic	enough	no		moderate
R8	little enough	little enough	little	automatic	enough	yes		good
R9	little enough	little enough	medium	manual	little enough	no		poor
R10	little enough	little enough	medium	manual	little enough	yes		poor
R11	little enough	little enough	medium	manual	enough	no		poor
R12	little enough	little enough	medium	manual	enough	yes		moderate
R13	little enough	little enough	medium	automatic	little enough	no		poor
R14	little enough	little enough	medium	automatic	little enough	yes		moderate
R15	little enough	little enough	medium	automatic	enough	no		moderate
R16	little enough	little enough	medium	automatic	enough	yes		moderate
R17	little enough	little enough	many	manual	little enough	no		poor
R18	little enough	little enough	many	manual	little enough	yes		poor
R19	little enough	little enough	many	manual	enough	no		poor
R20	little enough	little enough	many	manual	enough	yes		poor
R21	little enough	little enough	many	automatic	little enough	no		poor
R22	little enough	little enough	many	automatic	little enough	yes		poor
R23	little enough	little enough	many	automatic	enough	no		poor
R24	little enough	little enough	many	automatic	enough	yes		moderate
R25	little enough	enough	little	manual	little enough	no		moderate
R26	little enough	enough	little	manual	little enough	yes		moderate
R27	little enough	enough	little	manual	enough	no		moderate
R28	little enough	enough	little	manual	enough	yes		good
R29	little enough	enough	little	automatic	little enough	no		moderate
R30	little enough	enough	little	automatic	little enough	yes		good

IF-4	Disabled parking spaces	Entrance ramps	Entrance steps	Entry door type	Sidewalk ramps	Tactile paving	THEN	Disabled condition
R31	little enough	enough	little	automatic	enough	no		good
R32	little enough	enough	little	automatic	enough	yes		good
R33	little enough	enough	medium	manual	little enough	no		poor
R34	little enough	enough	medium	manual	little enough	yes		moderate
R35	little enough	enough	medium	manual	enough	no		moderate
R36	little enough	enough	medium	manual	enough	yes		moderate
R37	little enough	enough	medium	automatic	little enough	no		moderate
R38	little enough	enough	medium	automatic	little enough	yes		moderate
R39	little enough	enough	medium	automatic	enough	no		moderate
R40	little enough	enough	medium	automatic	enough	yes		good
R41	little enough	enough	many	manual	little enough	no		poor
R42	little enough	enough	many	manual	little enough	yes		poor
R43	little enough	enough	many	manual	enough	no		poor
R44	little enough	enough	many	manual	enough	yes		moderate
R45	little enough	enough	many	automatic	little enough	no		poor
R46	little enough	enough	many	automatic	little enough	yes		moderate
R47	little enough	enough	many	automatic	enough	no		moderate
R48	little enough	enough	many	automatic	enough	yes		moderate
R49	enough	little enough	little	manual	little enough	no		moderate
R50	enough	little enough	little	manual	little enough	yes		moderate
R51	enough	little enough	little	manual	enough	no		moderate
R52	enough	little enough	little	manual	enough	yes		good
R53	enough	little enough	little	automatic	little enough	no		moderate
R54	enough	little enough	little	automatic	little enough	yes		good
R55	enough	little enough	little	automatic	enough	no		good
R56	enough	little enough	little	automatic	enough	yes		good
R57	enough	little enough	medium	manual	little enough	no		poor
R58	enough	little enough	medium	manual	little enough	yes		moderate
R59	enough	little enough	medium	manual	enough	no		moderate
R60	enough	little enough	medium	manual	enough	yes		moderate
R61	enough	little enough	medium	automatic	little enough	no		moderate
R62	enough	little enough	medium	automatic	little enough	yes		moderate
R63	enough	little enough	medium	automatic	enough	no		moderate
R64	enough	little enough	medium	automatic	enough	yes		good
R65	enough	little enough	many	manual	little enough	no		poor
R66	enough	little enough	many	manual	little enough	yes		poor
R67	enough	little enough	many	manual	enough	no		poor
R68	enough	little enough	many	manual	enough	yes		moderate
R69	enough	little enough	many	automatic	little enough	no		poor
R70	enough	little enough	many	automatic	little enough	yes		moderate
R71	enough	little enough	many	automatic	enough	no		moderate
R72	enough	little enough	many	automatic	enough	yes		moderate
R73	enough	enough	little	manual	little enough	no		moderate
R74	enough	enough	little	manual	little enough	yes		good
R75	enough	enough	little	manual	enough	no		good
R76	enough	enough	little	manual	enough	yes		good
R77	enough	enough	little	automatic	little enough	no		good
R78	enough	enough	little	automatic	little enough	yes		good
R79	enough	enough	little	automatic	enough	no		good
R80	enough	enough	little	automatic	enough	yes		good
R81	enough	enough	medium	manual	little enough	no		moderate

IF-4	Disabled parking spaces	Entrance ramps	Entrance steps	Entry door type	Sidewalk ramps	Tactile paving	THEN	Disabled condition
R82	enough	enough	medium	manual	little enough	yes		moderate
R83	enough	enough	medium	manual	enough	no		moderate
R84	enough	enough	medium	manual	enough	yes		good
R85	enough	enough	medium	automatic	little enough	no		moderate
R86	enough	enough	medium	automatic	little enough	yes		good
R87	enough	enough	medium	automatic	enough	no		good
R88	enough	enough	medium	automatic	enough	yes		good
R89	enough	enough	many	manual	little enough	no		poor
R90	enough	enough	many	manual	little enough	yes		moderate
R91	enough	enough	many	manual	enough	no		moderate
R92	enough	enough	many	manual	enough	yes		moderate
R93	enough	enough	many	automatic	little enough	no		moderate
R94	enough	enough	many	automatic	little enough	yes		moderate
R95	enough	enough	many	automatic	enough	no		moderate
R96	enough	enough	many	automatic	enough	yes		good

IF-5	Comfort	Safety	Security	Disabled condition	THEN	PTI
R1	low comfort	low safety	low security	low		poor
R2	low comfort	low safety	low security	moderate		poor
R3	low comfort	low safety	low security	high		poor
R4	low comfort	low safety	moderate security	low		poor
R5	low comfort	low safety	moderate security	moderate		poor
R6	low comfort	low safety	moderate security	high		moderate
R7	low comfort	low safety	high security	low		poor
R8	low comfort	low safety	high security	moderate		moderate
R9	low comfort	low safety	high security	high		moderate
R10	low comfort	moderate safety	low security	low		poor
R11	low comfort	moderate safety	low security	moderate		poor
R12	low comfort	moderate safety	low security	high		moderate
R13	low comfort	moderate safety	moderate security	low		poor
R14	low comfort	moderate safety	moderate security	moderate		moderate
R15	low comfort	moderate safety	moderate security	high		moderate
R16	low comfort	moderate safety	high security	low		moderate
R17	low comfort	moderate safety	high security	moderate		moderate
R18	low comfort	moderate safety	high security	high		good
R19	low comfort	high safety	low security	low		poor
R20	low comfort	high safety	low security	moderate		moderate
R21	low comfort	high safety	low security	high		moderate
R22	low comfort	high safety	moderate security	low		moderate
R23	low comfort	high safety	moderate security	moderate		moderate
R24	low comfort	high safety	mod. security	high		moderate
R25	low comfort	high safety	high security	low		moderate
R26	low comfort	high safety	high security	moderate		moderate
R27	low comfort	high safety	high security	high		good
R28	moderate comfort	low safety	low security	low		poor
R29	moderate comfort	low safety	low security	moderate		poor
R30	moderate comfort	low safety	low security	high		moderate
R31	moderate comfort	low safety	moderate security	low		poor
R32	moderate comfort	low safety	moderate security	moderate		moderate
R33	moderate comfort	low safety	moderate security	high		moderate
R34	moderate comfort	low safety	high security	low		moderate

IF-5	Comfort	Safety	Security	Disabled condition	THEN	PTI
R35	moderate comfort	low safety	high security	moderate		moderate
R36	moderate comfort	low safety	high security	high		moderate
R37	moderate comfort	moderate safety	low security	low		poor
R38	moderate comfort	moderate safety	low security	moderate		moderate
R39	moderate comfort	moderate safety	low security	high		moderate
R40	moderate comfort	moderate safety	moderate security	low		moderate
R41	moderate comfort	moderate safety	moderate security	moderate		moderate
R42	moderate comfort	moderate safety	moderate security	high		moderate
R43	moderate comfort	moderate safety	high security	low		moderate
R44	moderate comfort	moderate safety	high security	moderate		moderate
R45	moderate comfort	moderate safety	high security	high		good
R46	moderate comfort	high safety	low security	low		moderate
R47	moderate comfort	high safety	low security	moderate		moderate
R48	moderate comfort	high safety	low security	high		moderate
R49	moderate comfort	high safety	moderate security	low		moderate
R50	moderate comfort	high safety	moderate security	moderate		moderate
R51	moderate comfort	high safety	moderate security	high		good
R52	moderate comfort	high safety	high security	low		moderate
R53	moderate comfort	high safety	high security	moderate		good
R54	moderate comfort	high safety	high security	high		good
R55	high comfort	low safety	low security	low		poor
R56	high comfort	low safety	low security	moderate		moderate
R57	high comfort	low safety	low security	high		moderate
R58	high comfort	low safety	moderate security	low		moderate
R59	high comfort	low safety	moderate security	moderate		moderate
R60	high comfort	low safety	moderate security	high		moderate
R61	high comfort	low safety	high security	low		moderate
R62	high comfort	low safety	high security	moderate		moderate
R63	high comfort	low safety	high security	high		good
R64	high comfort	moderate safety	low security	low		moderate
R65	high comfort	moderate safety	low security	moderate		moderate
R66	high comfort	moderate safety	low security	high		moderate
R67	high comfort	moderate safety	moderate security	low		moderate
R68	high comfort	moderate safety	moderate security	moderate		moderate
R69	high comfort	moderate safety	moderate security	high		good
R70	high comfort	moderate safety	high security	low		moderate
R71	high comfort	moderate safety	high security	moderate		good
R72	high comfort	moderate safety	high security	high		good
R73	high comfort	high safety	low security	low		moderate
R74	high comfort	high safety	low security	moderate		moderate
R75	high comfort	high safety	low security	high		good
R76	high comfort	high safety	moderate security	low		moderate
R77	high comfort	high safety	moderate security	moderate		good
R78	high comfort	high safety	moderate security	high		good
R79	high comfort	high safety	high security	low		good
R80	high comfort	high safety	high security	moderate		good
R81	high comfort	high safety	high security	high		good

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