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Irina Pticina

INTEGRAL ESTIMATION OF URBAN PUBLIC TRANSPORT SYSTEM SERVICE QUALITY FROM THE END-USERS POINT OF VIEW

Summary of the promotion work
to obtain the scientific degree of
Doctor of Science in Engineering (Dr.sc.ing.)
Scientific area "Transport and Communications",
scientific subarea “Telematics and Logistics”

Scientific supervisor:
Dr.sc.ing., professor
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OFFICIAL REVIEWERS:

The defence of the thesis will be held at _________ at _____ o'clock at the special Promotion Council of Transport and Telecommunication Institute on award of a doctor's degree at 1, Lomonosova Street, Conference Hall 130, Riga, Latvia, tel. +371 67100594, fax: +371 67100535.

CONFIRMATION

I hereby confirm that I have developed the promotion work that is presented to the promotion Council of Transport and Telecommunication Institute to obtain the scientific degree of Doctor of Science in Engineering. The promotion work has not ever been presented to any other promotional council to obtain the scientific degree.

April 2, 2015 I. Pticina

The promotion work is written in English, it contains an introduction, 4 chapters, conclusions, 41 figures, 57 tables, 26 formulas, 186 pages, and 9 appendixes. Bibliography contains 162 sources.

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CONTENTS

ANNOTATION

The thesis of Irina Pticina “Integral estimation of urban public transport system service quality from the end-users point of view”. The scientific supervisor is Dr.sc.ing., professor Irina Yatskiv.

Work is devoted to a problem of estimation of urban public transport system service quality from the customer’s point of view. The analysis of the existing methods of urban public transport systems service quality estimation is carried out. There is also considered experience of European countries. A methodology of Urban Public Transport System Quality Index (UPTQI) on the basis of the composite indicator is developed. A comparison of quality indicators of public transport system services is carried out, on the basis of which: classification of quality indicators is offered and requirements to quality indicators, which need to be included in UPTQI, are developed. As result a set of 51 public transport system service quality indicators is developed, which cover various aspects of service quality of public transport system: availability, accessibility, information, time, comfort, customer care, security and environment. Recommendations on the organization of transport surveys are developed to obtain necessary primary data for public transport system service quality indicators. As a key step in the algorithm of UPTQI construction, four methods of the weight coefficients estimation are offered and analysed: the method based on principal components analysis, benefit of the doubt approach, the method based on the analytic hierarchy process and equal weighting. Algorithm of the choice of the missing data imputation method on the basis of the analysis of available data set is offered and realized. The methodology is approved for 62 European cities. The analysis of the influence of the methods of weight coefficients estimation and methods of missing data imputation to UPTQI value is carried out. The analysis of data availability is carried out to estimate the service quality of Riga’s public transport system. The recommendations for transport surveys carrying out are developed, and procedures and tools for public transport system inventory survey and household travel survey are offered.

1. ACTUALITY AND MOTIVATIONS OF THE RESEARCH

European cities and their populations are facing everyday problems related to transport and mobility: congestion, air and noise pollution, inefficient public transport services and accidents. Withal the count of urban inhabitants in Europe is more than 73 per cent and constantly growing, it is expected to be more than 80 per cent by 2050. 67.83% of the population of Latvia are city dwellers. The citizens of Latvian cities (in particular, this applies to the city of Riga) also face everyday consequences of unresolved transport problems.

The current development of urban areas needs an integral approach in the context of its sustainable development. First of all, what is meant here is ensuring the quality of people's life, based on three basic viewpoints: economic, social, and environmental. The term "sustainable transport" came into use as a logical follow-up of the term "sustainable development". Sustainable transport should first consider the needs of the population and should be environmentally friendly, affordable, and safe. From the sustainability viewpoint, the strongest emphasis is currently laid not so much on the construction of new objects of transport infrastructure as the efficient use of the existing ones. The search for solutions in this field is currently following two main directions: the use of state-of-the art technologies for urban traffic control (creation of the so-called intelligent transport systems) and the creation of a public transport system attractive for users. Public transport plays the most important role in social and economic life of the city.

According to the Latvian Republic "Law on Public Transport Services" public transport services – regular carriage of passengers by public transport vehicles organised by the ordering party and available to residents, which the passengers may use in accordance with the procedures specified in regulatory enactments. According to the data collected by LR Central Statistics Office, the number of passengers of the Riga public transport has dropped significantly within the period from 2006 to 2010 for several reasons: the economic crisis, depopulation in the country, and the higher travel costs without any improvement of public transport service quality to the appropriate level. From 2010 onwards, the number of passengers in the Riga public transport has been increasing gradually. To carry on this trend should be suggested a program of increasing of attractiveness of public transport. Integral part of this program has to be the system of actions for improvement of PT service quality, which has to include both evaluation stages and monitoring of the current level of quality and the analysis of the most significant aspects of quality to maintain special measures aimed at these essential components of quality.

The analysis of this question about the transport inspections in Riga and questions on assessing the quality of services became the motivating moment for a problem definition of this research.

2. GOAL AND TASKS OF THE RESEARCH

The ***goal*** of the research – development of the methodology of urban public transport system service quality estimation from end-users point of view.

In order to implement the goal of the study the following ***tasks*** were proposed:

1) The review of the existing methods for service quality estimation and the approaches to estimation of urban public transport service quality.
2) Comparative analysis of UPTS service quality indicators in terms of consumer's viewpoint and data collection methods.
3) The development of methodology for constructing the UPTS service quality indicator based on the composite indicator theory, with a detailed elaboration of the algorithm steps.
4) Working out the requirements to quality indicators used for constructing the UPTS service quality index, and the compilation of list of such indicators.
5) The development of an algorithm for missed values imputation method selection, based on the analysis of data available.
6) Performing the analysis of the influence of weight coefficient estimation method and missed data imputation methods upon the value of the developed service quality indicator with respect to UPTS.
7) The approbation of the suggested methodology with a view of collecting actual data for European cities.
8) The estimation of the Riga's UPTS service quality based on the suggested methodology, and making recommendations for data collection to estimate the UPTS service quality.

The ***object*** of investigation is an urban public transport system service quality.

The ***subject*** of investigation is an algorithm of composite indicator construction for urban public transport system service quality estimation.

3. DEGREE OF THE THEME RESEARCH

The first chapter of the thesis gives an overview of research in the field of estimating the quality of service of urban public transport system. The estimation of urban public transport system service quality is a complicated, multistage, and multi-dimensional problem; therefore the review was performed in several directions (Figure 1).

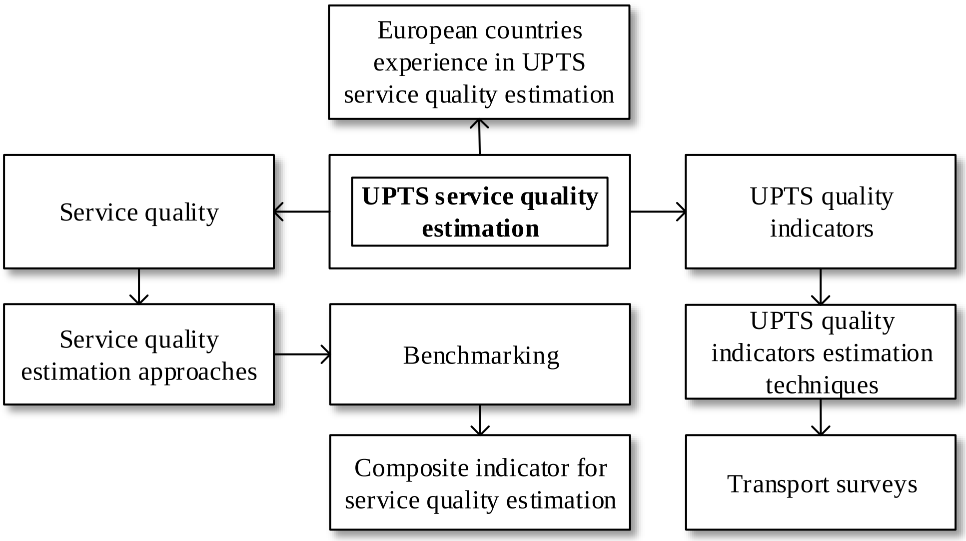

Figure 1. The direction of the literature review

The most important role in the development of the concept of quality belongs to the following scientists: Deming, Juran, Parasuraman and Grönroos. The quality philosophy and quality estimation methods developed by them are fundamental. The most well-known service quality models are the Technical and functional quality model, offered by Grönroos in 1984 and GAP model, introduced by Parasuraman. The research of Parasuraman and others of a GAP service quality model was refined with their subsequent scale named SERVQUAL for measuring customers' perceptions of service quality. The SERVQUAL model is frequently used as a basis for development of other service quality estimation models – as for example, SERVPERF proposed by Cronin and Taylor (1992), the model proposed by Lee et al (2000), the Avkiran model (1994) etc. The methodology as Customer Satisfaction Index (CSI) developed by Stockholm School of Economics has also become a frequent practice. This is an index, which is calculated based on the personal interview method (2014). On the base of CSI have been developed such indices as American Customer Satisfaction Index (ACSI), European Customer Satisfaction Index (ECSI), Swedish Customer Satisfaction Barometer (SCSB) and Norwegian Customer Satisfaction Barometer (NCSB).

The following scientists' works are devoted to the public transport system service quality estimation: Polus (1978), Thomson (1983), Rood (1997), Polzin et al. (2002), Murray A. (2001), Friman and Garling (2001), Friman (2004), Bhat, (2005), Jabkowski P. (2005), Abreha D. (2007), Liu and Sinha (2007), Los (2007), Beirão (2007), Fu and Xin (2007), Seco A. and Gonçalve J. (2007), Coelho, et al. (2008), Fellesson (2008), Litman (2008), Tyrinopoulos and Aifadopoulou (2008), Nathanail (2008), Chen, et al. (2009), Eboli and Mazzulla (2011), Litman (2011), Maskeliunaite and Sivilevicius (2012), Anderson, et al. (2013), Gahlot et al. (2013), Dragu, et al. (2013), Cascetta and Cartenì (2014) and many others. Their work is mainly devoted to the analysis of quality indicators, or use one of the above-mentioned models of quality estimation.

There are various EU research projects dedicated to the development of methodology for estimating UPTS quality and many scientists are involved in these projects. The following scientific projects pertaining to the field of UPTS service quality estimation should be mentioned: QUATTRO (EU Transport RTD program, 1998), EQUIP (EU Transport RTD program, 2000), and PORTAL (EU Transport RTD program, 2003), MEDIATE (2008-2010) etc. A great attention has been always paid to quality and efficiency of transport system in USA. American Transit Cooperative Research Program (TCRP) implemented a comprehensive research program, with analysing performance measurement system of American public transport companies, in order to establish a guidebook for developing a transport performance measuring system.

Now in the world practice to an assessment of competitiveness of regions and the development of a strategy to improve it the benchmarking is widely applied. The following scientists used of benchmarking principles in the urban public transport sector: Taylor, Randall, Trompet, Henning, etc. There are some scientific and practical projects connected with the benchmarking in public transport, but they are very few in number and they cover some definite aspects of management only: Pilot exercise of benchmarking local passenger transport systems, 1998 – 1999; the European Commission's Urban Transport Benchmarking Initiative, 2003 – 2006; BEST – Benchmarking European Service of public Transport, 2005 – nowadays.

The common famous approach in benchmarking in the multivariate case is to construct an integral (scalar) indicator and that may be used successfully for comparison and the development analysis instead of a set of parameters: Technology Achievement Index (TAI), Worldwide Governance Indicators, General Indicator of Science and Technology (NISTEP, Japan), Internal Market Index (European Commission), the Globalisation Index (G-Index) (World Markets Research Centre), Logistics Performance Indicator (LPI) etc. In 2004 (OECD, 2004) the definition of composite indicator have been appeared. On the construction of a composite indicator the works by Saisana (2002) and Nardo et al (2008) were dedicated. The problem of developing the integral indicator is a subject that quite a number of theoretical researches by Aivazyan and Borodkin (2006), Gertsbakh & Yatskiv (2006) are focused on. There are some works which are devoted of the integral indicator constructing for an estimation of the transport system quality: Peña (1997), Seco and Gonçalves (2007), Hermans (2009), Coelho, et al. (2008).

In the course of the literature analysis, not a single reference to the urban public transport system service quality index had been found which would be built on the basis of a composite indicator and which would evaluate UPTS service quality from the user's perspective, taking into account all the components of quality. This was the motivation for this study.

4. METHODOLOGY AND THE METHODS OF RESEARCH

The following theories and methods have been used in the work: the system approach, the methods of mathematical statistics, expert methods, the methods of quality theory in context of service quality estimation, methods of survey and transport system analysis. To approve of developed methodology and to evaluate the influence of different methods on the UPTS service quality index value the case study have been conducted. The following tools were used: statistical analysis package Statistica 7, statistical data analysis programs R and RStudio, software for engineering calculations MATCAD 2014, the spread sheet application software MS Excel; for developed algorithm coding it was used the programming language C#.

5. SCIENTIFIC NOVELTY OF THE WORK

In the course of the work, the following results, which are new to the transportation engineering science, have been obtained:

- ✓ Methodological approach to design urban public transport system service quality index (UPTQI) on the basis of theory of composite indicator construction.
- ✓ The taxonomy of urban public transport system service quality indicators that should be included as sub-indicators in UPTQI.
- ✓ The procedure of the choice of a missing values imputation method on the basis of the analysis of the available data.
- ✓ Recommendation and necessary tools for data obtaining.
- ✓ Analysis accessibility of data for holistic estimation of Riga public transport system service quality.

6. PRACTICAL VALUE AND REALIZATION OF THE WORK

The proposed methodology and procedures are primarily of practical importance for the decision-taking persons in the field of UPTS service provision, monitoring and quality estimation, municipality, public transport operators, planners and organizes of transport surveys.

7. APPROBATION OF THE RESEARCH

The results of research were reported at 12 scientific and research conferences in Lithuania, Belgium, Croatia, Portugal, Belorussia and Latvia.

The main work results were presented for discussion on the seminar of European project TUD COST Action TU0804 Survey Harmonisation with New Technologies Improvement (SHANTI). The fragments of the proposed procedures were realized in the municipal projects: "Pedestrian and transport flows analysis for pedestrian street creation in Riga city", 2011; "Freight traffic flow research and rerouting from Riga city centre", 2014; "Traffic flow study and modelling of the Hanzas-Sporta-Skanstes-Vesetas streets area", 2015.

8. STRUCTURE OF THE THESIS

The promotional work consists of an introduction, 4 chapters, a conclusion, a list of references, and 9 appendices. The work comprises 186 pages and includes 41 figures, 57 tables and 26 formulas. The list of references includes 162 sources. The structure of the work is as follows:

Introduction is dedicated to considering the relevancy of the subject of thesis, formulating the research goal and objectives; the object and subject of research and motivation; the degree of the theme study, methodology and methods of research.

In the first chapter of the thesis, a review of service's quality estimation methodologies is presented, the characteristics of UPTS service quality are considered, and the classification of quality indicators has been made. Furthermore, service quality indicator estimation techniques are presented and the European countries' experience of estimation of urban public transport quality is considered.

In the second chapter, the composite indicator constructing methodology is examined; the methodology for construction of the composite indicator-based quality index of urban public transport (UPTQI) has been proposed; the list of urban public transport system service quality indicators, as well as the algorithm for selection of an appropriate missing data imputation method have been proposed; furthermore, the data collection methodology and the sensitivity analysis performance methodology have been proposed.

In the third chapter, the suggested methodology for construction UPTQI was applied to estimate the service quality of urban public transport with respect to European cities – as a case study, which has been used for numerical experiments.

In the fourth chapter, the UPTQI value with respect to Riga had been analysed; an analysis of the availability of service quality data for the Riga public transport has been made; finally, suggestions and recommendations for estimating the urban public transport system service quality indicators had been presented.

The work results are presented in the works' *conclusions*.

Nine *appendices* include the list of UPTS quality indicators, entity–relationship model of quality indicators database, the examples of tools and procedures for transport surveys, the description of realised software tools, data of numerical example and the realised weight coefficient calculation procedure.

9. THE THESES SUBMITTED FOR DEFENSE

1) The methodology of urban public transport system service quality index (UPTQI) development.
2) The requirements of the urban public transport system service quality indicator.
3) The set of quality indicators and their estimation methods for UPTQI constructing.
4) The approach of a missing data imputation method choosing on the basis of the analysis of the available dataset.

10. REVIEW OF THE PRINCIPAL RESULTS OF THE RESEARCH

10.1. Review of urban public transport system service quality estimation approaches

The transport service quality is a set of properties and performance indicators characterizing the transportation process and transport system and stipulating their compliance with regulatory requirements. The general requirements to quality indicators should reflect valid interests of passengers; as regards public transport, they should reflect interests of the society as well. Organization of passenger transport, by virtue of its large non-uniformity both in terms of time and distance, is a very complex socio-technical system that requires special approaches to estimating the quality of its services.

The main purpose of the UPTS is to meet the population’s demand for movements; the main function of UPTS is the provision of safe, reliable, punctual, affordable, environmentally friendly, and cost-effective transport services.

In 2002, the European standard EN 13816 Transportation – Logistics and services – Public passenger transport – Service quality definition, targeting and measurement was developed. It contains the definition of public transport system quality. According to the standard, the quality of public transport system service is characterizing by eight components: availability, accessibility, information, time, customer care, comfort, security and environment. Each component is characterizing by a set of quality indicators. The UPTS service quality indicators are of a different nature. The classification of UPTS service quality indicators have been carried out and 12 classification factors have been allocated (Figure 2).

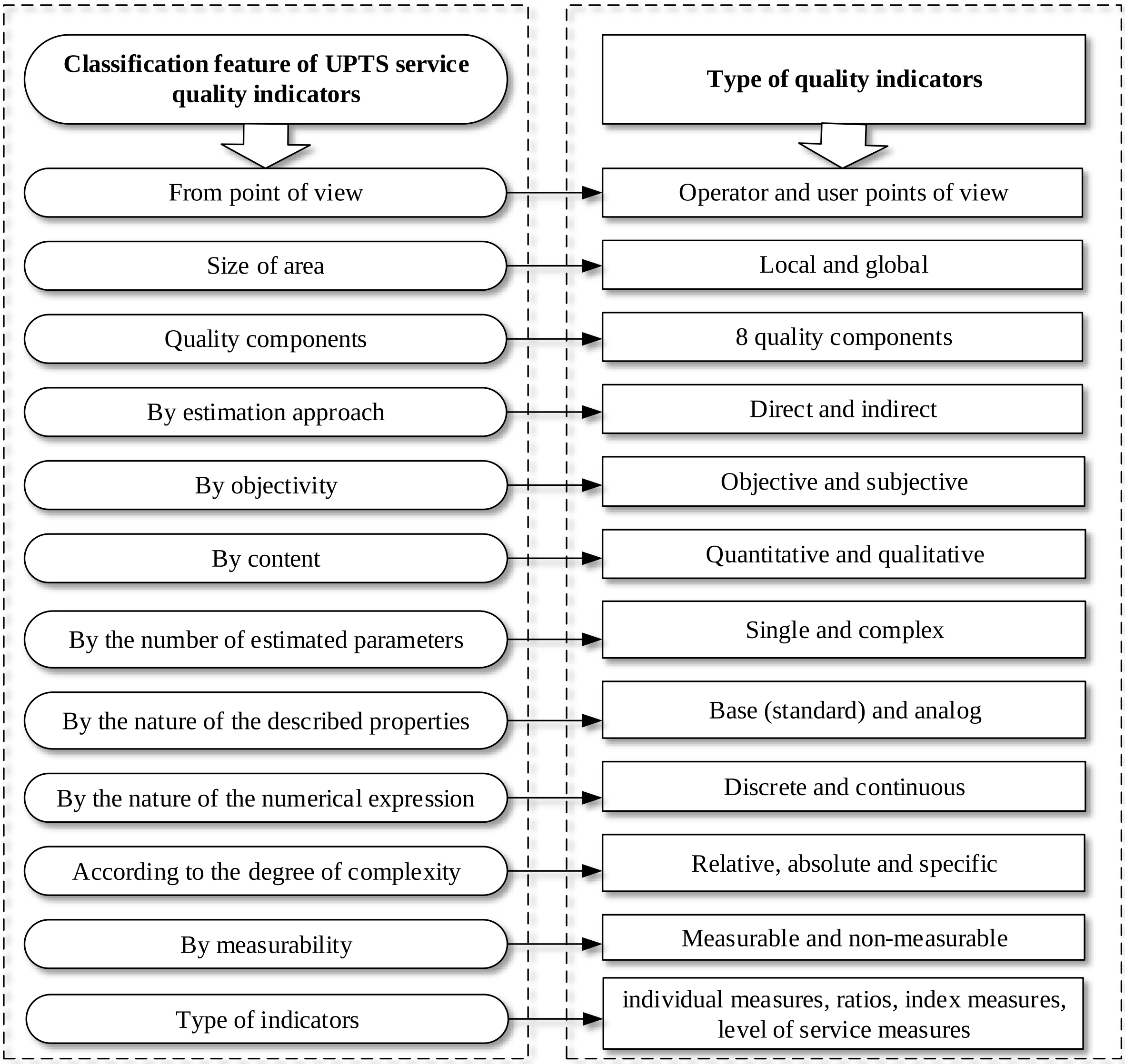

Figure 2. The structure of the quality indicators classification

Each of these factors determines the scale of measurements of quality indicators, data collection method, UPTS service quality component which quality indicator characterise. The quality of UPTS service can be looked at from two angles. One is the operator's (providers) attempt to minimize total operating costs of providing services; while the other is how much the services provided are utilized effectively in meeting its objectives and the needs of the users (customers).

The estimation of UPTS service quality indicator values can be carried out by direct performance measure, estimated performance measures or customer satisfaction surveys (Figure 3).

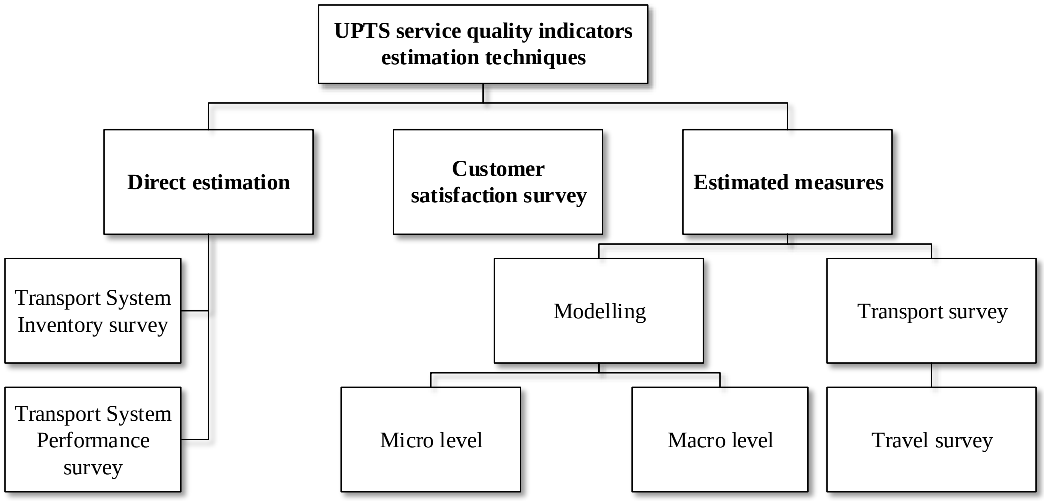

Figure 3. UPTS service quality indicators estimation techniques

Direct estimation allows one to estimate the actual quality and performance of the service by way of direct measurements of UPTS service quality indicators by virtue of transport system inventory and performance surveys. Thus, indicator values mainly characterizing UPTS accessibility and availability can be obtained, such as length of public transport network, the number of routes, the number of stops, etc. Estimated measures are sample-based measurements, like travel surveys allowing one to estimate the demand for the service; moreover, estimation based on transport system modelling is used (macroscopic, mesoscopic, and microscopic). On the base of such kind of models of transport systems can be estimated the following UPTS service quality indicators values: demand, vehicle loading, passenger flow (Gudowski & Wąs, 2006); travel speed, travel time, travel time variability (Kieu, et al., 2014); departure time, reliability (Ceder, 2007), (Yatskiv, et al., 2012), punctuality, dwell time (Li, et al., 2012), wait time, delay time; accessibility of PTN, walking accessibility to PT stops or terminals (Wibowo & Olszewski, 2005), surface coverage (von Ferber, et al., 2009); average transfer rates, etc.

The techniques of Customer Satisfaction Survey is highlighted as a class of its own which allows one to obtain values of subjective indices – such as UPTS users' satisfaction level with respect to various UPTS characteristics.

Table 1 shows the types of transport surveys used to collect UPTS service quality data, and the most popular methods used in specific surveys. The questionnaire are filled out either by operator's representative or questioner. The poll is carried out face-to-face, by paper and pencil interviewing, by computer assisted telephone interviewing (CATI) or computer assisted personal interviewing (CAPI). The use of Automatic Vehicle Location systems (AVL) and Automatic Passenger Counting Systems (APC) in PT vehicles allows one to receive information on travel time, timekeeping, punctuality and vehicle loading etc. quickly and

Table 1.

Types and methods of transport surveys

Type of survey	Subject of survey	Data that can be obtained by survey	Sample units	Sampling approach	Survey instrument	Survey method
Transport System Inventory survey	Infrastructure of UPTS	Characteristics of UPTS infrastructure: modes of transport, network length, the number of routes and stops, schedules, etc.	Public transport operators	All UPTS operators, random, multistage, systematic sampling	Questionnaire	Documentary Searches, PAPI, face to face CATI, CAPI
Transport System Performance survey	Performance of UPTS	Characteristics of UPTS performance: travel time, waiting time, vehicle load, system safety, delays, etc.	Public transport operators, Routes, Trips	All UPTS operators; for routes and trips: random, multistage, systematic sampling	AVL, APC, Questionnaire	By observers un PAPI, video
Travel survey	Trip	Trip characteristics: departure and destination points, travel time, modes, goal of trip, route, etc.; traveller's characteristics	Individuals / households	random, stratified sampling, multistage sampling, systematic, cluster sampling	Travel diary, GPS	face to face, PAPI, CATI, CAPI, CAWI, GPS trackers
Customer satisfaction survey	Level of satisfaction of UPTS services	General satisfaction in UPTS service - global satisfaction; level of satisfaction with the individual components of UPTS services - accessibility, comfort, travel time, etc. - specific satisfactions; significance of UPTS quality characteristics for users	individuals/ households	Random, stratified sampling, multistage sampling, systematic, cluster sampling	Questionnaire	face to face, PAPI, CATI, CAPI, CAWI

PAPI - Paper and Pencil Interviewing, CATI – Computer Assisted Telephone Interviewing, CAPI – Computer Assisted Personal Interviewing, CAWI - Computer Assisted Web Interviewing, APC - Automatic Passenger Counting Systems conveniently (in the form of database entries). Should the transport vehicles not be equipped with the above-stated devices, the survey is carried out through observers. To obtain information on demand for movement, the trip diary-based survey has become a frequent practice. This approach is based on collecting data describing household members within 24-hour period of time (or more), with the data used taken from trip diary. Nowadays, various mobile applications fixing respondent's movements through GPS have gained a wide circulation (Shena & Stophera, 2014).

To obtain data for indicators characterizing UPTS service quality, a number of different data sources are used. Therefore, to organize the collection of such data, a set of procedures including recommendations on selecting survey methods and tools should be developed.

The fulfilled review identified the problems of UPTS service quality estimation from users' point of view. First of all, despite the existence of the developed European standard EN 13816, there is lack of a unified consistent approach to UPTS quality estimation in Europe. Some European countries have developed standards of their own, based on the European standard. All of them are actually oriented towards PTS operators' performance. In European countries, there is lack of a consistent data collection technique based on UPTS service quality indicators. Moreover, the problem is that various institutions should be involved into the data collection process: PT operators, governmental institutions, and UPTS users themselves. To ensure data acquisition with respect to indicators characterizing UPTS service quality, a number of various data sources are used. Therefore, a set of procedures including various methods and tools should be developed to organize the collection of data of that kind.

Further, the service quality estimation is a complex task, since the service user himself is involved into the service delivery process. In is impossible to draw a qualitative comparison between the actual quality of public transport system in different cities and countries on the basis of this multivariate set of data. To draw the comparison between the urban public transports systems in various cities, a composite indicator-based index can be used, which, by way of combining all the UPTS quality indicators into a single scalar quantity, would enable one to perform the benchmarking of UPTS of the cities in its multidimensional issue. To construct such an index, a technique should be suggested which would contain a list of used UPTS service quality indicators, the methodology of data collection, the database structure to store the indicator values, the guidelines for selecting data processing methods, and the method for calculating such an index. In this work, the technique of UPTS service quality index construction based on composite indicator is suggested.

10.2. Urban public transport system service quality estimation methodology based on composite indicator

To estimate the urban public transport quality system from passenger's viewpoint, we suggest a procedure for constructing an UPTS service quality index - the **Urban Public Transport Quality Index (UPTQI)**. This index built on the basis of composite indicator will enable one to unite a large number of UPTS quality indices into a single scalar, which, in turn, will allow one to compare UPTS quality service in different cities, rank the cities and trace the dynamics of UPTS quality service development in the course of time.

We define the UPTQI as the sum of product of the UPTS service quality indicators values and weight coefficients, where weight coefficients values reflect the each quality indicator investment amount to the UPTQI:

$$UPTQI_i^t = \sum_{j=1}^{M} I_{ij}^t w_j, \tag{1}$$

where:

- $UPTQI_i^t$ – value of UPTQI for city *i* (*i*=1…*N*, *N* – number of cities) in time *t*,
- I_{ij}^t – value of normalised *j*-th quality indicators (*j*=1…*M*, *M* – number of quality indicators) for city *i* in time *t*,
- w_j – weight associated with *j*-th quality indicator.

The UPTQI value is calculated for each city with respect to a given time. As the given time, a year of quality indicators data collection is used.

The UTQI construction methodology is presented on Figure 4 and consists of seven stages: creating the list of UPTS service quality indicators, data collection, preliminary stage, weight coefficients estimation, aggregation, uncertainty and sensitivity analysis and result interpretation and visualization.

In suggested methodology special attention will be paid to the formation of the list of UPTS service quality indicators, selection of the appropriate method for missing data imputation, and the weight coefficient estimation method.

- **Creating the list of UPTS service quality indicators**

Essential requirements for quality indicators selection for UPTS service quality estimation from passengers' point of view are:

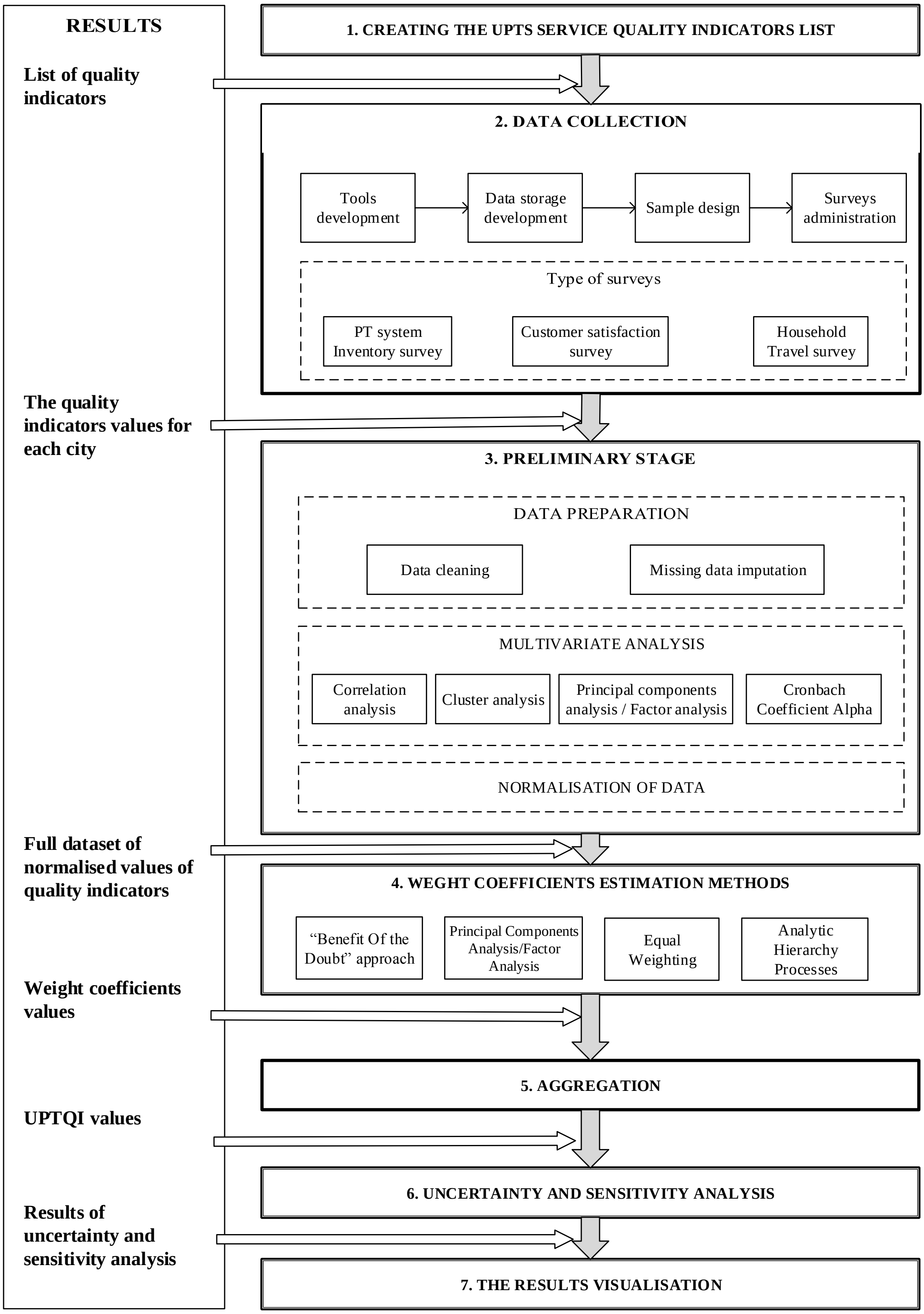

Figure 4. Stages of UPTQI construction process

- the indicators should allow estimate UPTS service quality from passengers point of view, i.e. there must be a clear relation with the general objectives and requirements of passengers, such as minimisation of travel time, cost, generalized time or costs (as combination of previous), environmental preservation, safety to survive), and so on; the indicators should reflect the condition of UPTS as a whole;
- the data should cover all the UPTS service quality components;
- the indicators must take into account city features, city size (population and land (urban, city area), motorization level, the average income of city tenants, and GDP per capita;
- the essential information for the indicators estimation must be easily obtainable and preferably be pre-existing;
- the time and costs for essential data acquisition for indicators' quantification must be taken into account in its selection;
- measurement indicators and the data used must be reliable;
- special care should be taken to prevent data redundancy and duplication;
- the indicators must allow the perception of each individual indicator influence on the urban system.

According to these requirements, 51 UPTS service quality indicators have been selected for UPTQI construction. The indicators are subdivided by eight components of UPTS quality. The respective code and definition have been assigned to each indicator; furthermore, list of necessary data, calculating method, unit of measurement, and the data source have been attached to each indicator as well.

- **Data collection**

As the main sources for UPTS service quality indicators, various types of transportation surveys are used: UPTS inventory survey, household travel survey and customer satisfaction survey. Apart from transportation surveys, the following is used: census data, traffic police data, fire and rescue service's data, and security police data. The methods recommended for carrying out the above-stated surveys are shown on Figure 5.

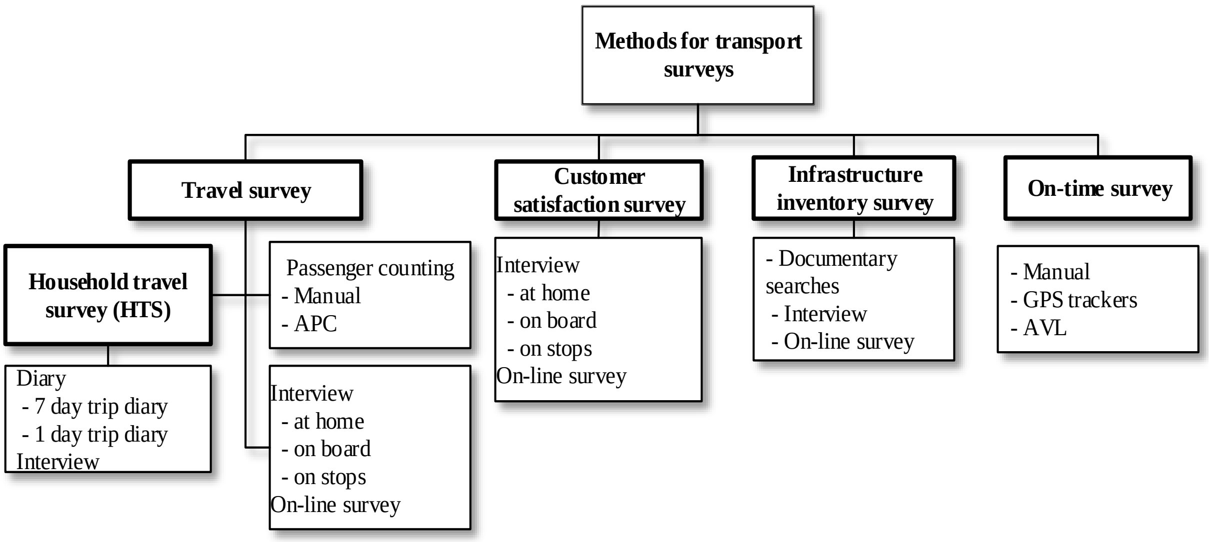

Figure 5. Recommended survey methods for data collection

Each kind of survey implies the use of definite methods for data collection. In most cases, a set of methods is used.

- **Preliminary stage**

At the preliminary stage, data processing and preliminary analysis is made. This stage includes four steps: data cleaning, missing data imputation, multivariate analysis and normalisation of data.

In process of ***data cleaning***, data mismatch errors are detected and corrected to improve the data quality. Data errors may occur in process of working out questionnaires, during data collection, data entry into the database or electronic tables. To identify errors, the following is applied: manual data control and statistical methods of data analysis with the aid of descriptive statistics: minimum/maximum, analysis of emissions, root-mean-square deviation and dispersion, and analysis of missing values.

A commonly encountered problem of index constructing is the missing data problem. There are many classical approaches for work with incomplete data set, one of them – imputation of missing data. As there are no universal recommendations for usage of this or that method of the imputation of the missing data and results of its usage depend on character of a solved problem, on a set of variables, and on model of skips. The author presumes that the selection of *missing data imputation* method should be done, taking into account the specific character of the dataset available and offers the algorithm of the best method selection.

Algorithm of the choice of the missing data imputation method.

The algorithm is based on the analysis of the impact of the missing data imputation methods upon UPTQI value with respect to those objects (cities) from the full set, which have no skips whatever.

The input data for this algorithm are:

- *M* – number of UPTS quality indicators,
- *N* – number of cities, L cities from them don't have any skips in the quality indicators values,
- *N-L* – number of cities that have missing data.

The appropriate method for the missing data imputation must be selected for UPTQI constructing for the full dataset (N cities). The five-stage algorithm of the choice of the missing data imputation method for the available dataset of the quality indicators values is presented at Figure 6.

Step 1. The UPTQI for cities without missing data (*L* cities) is estimated and ranks of cities are determined. These values are called by the original values of UPTQI ($UPTQI_{orig}$) and of city rank (R_{orig}).

Step 2. Some values from the data set where quality indicators values are known (*L* cities) are removed (proportionally to missing values in the complete data set) and then are substituted. For imputation of the missing data in considered dataset the some methods were used.

Step 3. The influence of missing data imputation methods on the UPTQI value is investigated. The values of *UPTQI* and rankings (*R*) of *L* cities with respect to all cases of missing values imputation are calculated. Afterwards, the received *UPTQI* and *R* values will be compared to original values $UPTQI_{orig}$ and city rankings R_{orig} that had been calculated for the same cities – however, with no skip in data. Then the most appropriate method of missing data imputation will be selected for the given set. As the selection criteria are used the following:

- the Person's correlation between $UPTQI_{orig}$ and *UPTQI*,
- the Spearman's correlation between R_{orig} and *R*,
- the sum of squared deviations (SSD) UPTQI from $UPTQI_{orig}$ are used as selection criteria.

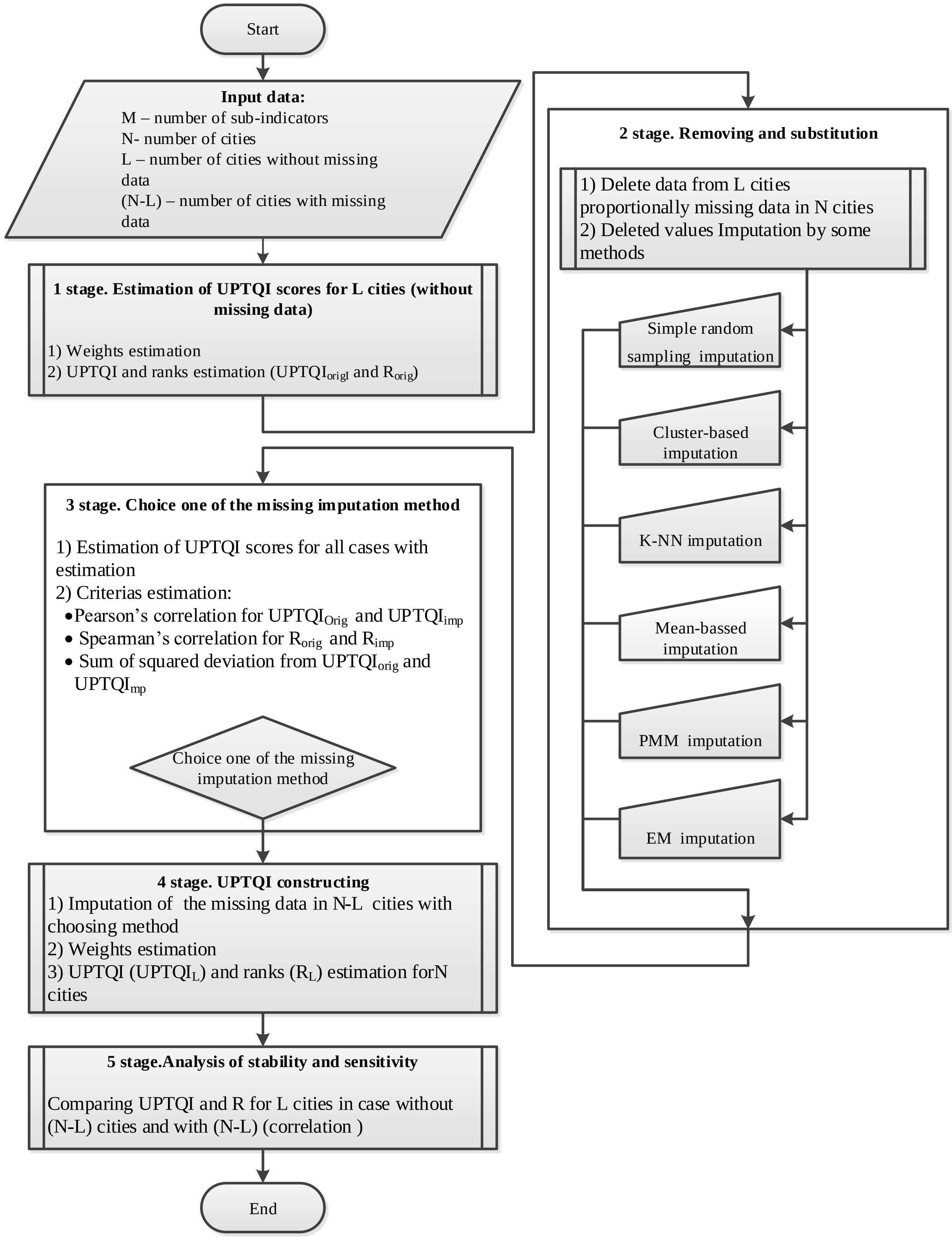

Figure 6. Algorithm of the choice of the missing data imputation method

Step 4. The missed values in the full set of data (*N* cities) by using the method selected at the third stage are imputed. The weight coefficients and values of *UPTQI* for all the cities ($UPTQI_N$) are calculated and cities rankings (R_N) are determined.

Step 5. The analysis for sensitivity and stability of results are performed. To do that, the values *UPTQI* and *R* that had no missed data (*L* cities) are compared – both when data on other cities is available and missing.

As the result of this algorithm is the recommendation of the use of the method of missing data imputation taking into account the available dataset.

A ***multivariate analysis*** should investigate the overall structure of the indicators, assess the suitability of the data set and explain the methodological choices, e.g. weighting. The following methods for statistical analysis are applied: cluster analysis, correlation analysis, principal components/factor analysis and Cronbach coefficient alpha.

- **Weight coefficients estimation**

This stage includes the selection of method for weight coefficient estimation and the direct estimation of those coefficients. To analyse the applicability of someone or other method for weighted coefficient estimation, we will apply a few methods from different groups when constructing UPTQI:

- methods based on statistical models: the method based on Principal Components analysis (PCA) and Benefit of the Doubt approach (BOD);
- based on participatory methods: the method based on the Analytic Hierarchy Process (AHP);
- Equal Weighting (EW).

Weights estimation based on principal components analysis model. At first, the correlation structure of the data was checked. It is needed for preliminary analysis of the common factors existing. Then identifying a certain number of latent factors smaller than the number of sub-indicators implies data representation and the factor structure rotation if necessary.

Let a_{pj}- the *p* factor loading for *j* variable and $D[f_p]$ - variance explained by the *p* factor. In this case introduce the normalization of factor loading as:

$$a_{pj\,norm} = \frac{a_{pj}^2}{D[f_p]}, \quad (2)$$

and the weight for *j* variable as maximum of factor loading multiplied the proportion of total variance for corresponding factor:

$$w_j = \max_p a_{pj\ norm} \frac{D[f_p]}{\sum_{r=1}^{R} D[f_r]}, \tag{3}$$

where:

- $a_{pj\ norm}$ - normalised p factor loading for j variable,
- $D[f_p]$ - variance explained by the p factor,
- R – number of factors,
- w_j – the weight for j variable.

Weights estimation based on benefit of the doubt approach. The method endogenously determines country-specific weights that explicitly take account of a country's own choices and achievements across primitive dimensions of performance. In this method, the UPTQI is defined as the actual/benchmark performance ratio and the weights are city specific. Optimal weights are obtained by solving the constrained optimisation as linear programming problem:

$$UPTQI_i^* = arg\,\max_{w_{ij}} \sum_{j=1}^{M} w_{ij} I_{ij}, \tag{4}$$

with following constraints:

$$\begin{cases} \sum_{j=1}^{M} w_{ij} I_{ij} \le 1, \\ w_{ij} \ge 0 \end{cases}. \tag{5}$$

Weights estimation based on the Analytic Hierarchy Process. The procedure of weight coefficients estimation contains six steps as follows:

Step 1. A hierarchy structure of UPTS service quality must be developed. Figure 7 shows the hierarchical structure of UPTS service quality and it consists of four levels: at the first level, there is the goal - UPTQI, at the second level - the quality components of UPTS, at the third level - the quality indicators of UPTS service, which are distributed by the quality criteria, at the fourth level – the cities with the values of quality indicators. The cities are alternatives in terms of the AHP method.

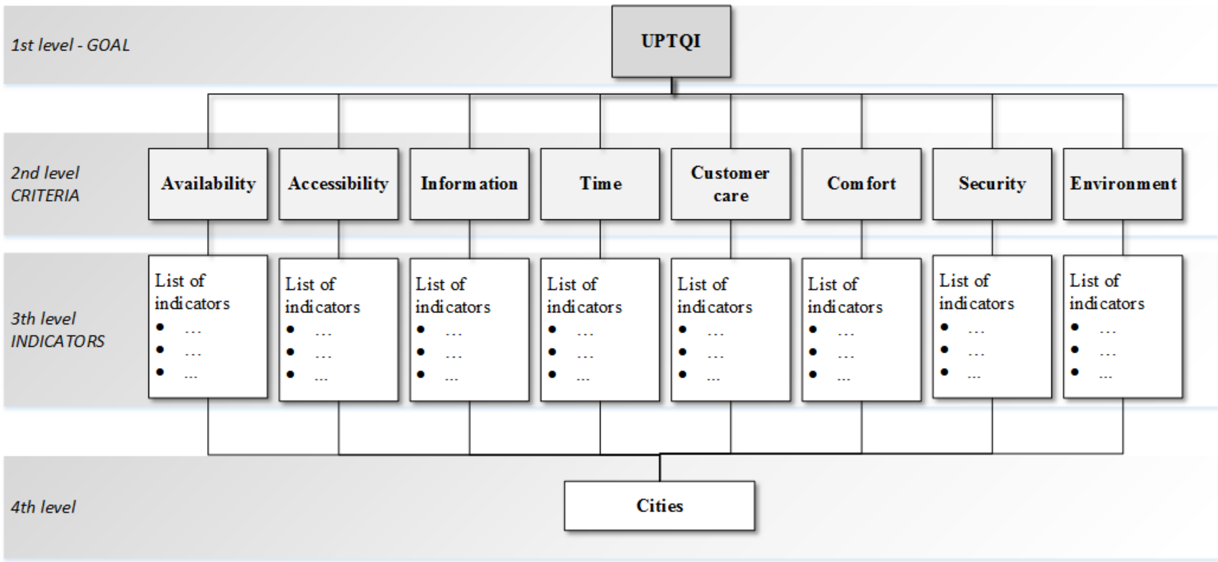

Figure 7. Hierarchy structure of UPTS quality

Let us denote as:

- K – the number of UPTS service quality criteria and equal to 8 for the hierarchy structure which is presented in the Figure 7*;*
- c^k – the elements of the hierarchy structure second level (the criteria of the UPTS service quality), where k=1..K;
- M^k – the number of quality indicators for k-th criteria;
- p^k_j – the elements of third level of the hierarchy structure (the UPTS service quality indicators), where k – the criterion number which includes the quality indicator j, j=1..M^k.

Step 2. The pairwise comparison matrices are built and filled based on the developed hierarchy. The structure of the matrix of pairwise comparisons for the 2nd level of hierarchy structure is shown in Equation 6.

$$H^0 = \begin{array}{c} \\ c^1 \\ c^2 \\ \ldots \\ c^K \end{array} \begin{array}{cccc} c^1 & c^2 & \ldots & c^K \\ \end{array}$$

$$H^0 = \begin{array}{c|cccc|} & c^1 & c^2 & \ldots & c^K \\ c^1 & 1 & h^0_{12} & \ldots & h^0_{1K} \\ c^2 & h^0_{21} = \dfrac{1}{h^0_{12}} & 1 & \ldots & h^0_{2K} \\ \ldots & \ldots & \ldots & \ldots & \ldots \\ c^K & h^0_{K1} = \dfrac{1}{h^0_{1K}} & h^0_{K2} = \dfrac{1}{h^0_{2K}} & \ldots & 1 \end{array} \quad (6)$$

where: h^0_{kl} – the degree value of preference of the element c^k over the element c^l, k=1..K, l=1..K.

Such sets of matrices are to be built for the pairwise comparisons of each member of the 3rd level (for quality indicators p^k_j) with respect to the elements of the 2nd level (the quality of the criteria c^k). To establish the relative importance of the elements of the hierarchy structure a scale of preferences from 1 to 9 is used.

Step 3. The consistency of expert opinions is checked. The consistency index (CI) and the consistency ratio (CR) were used.

$$CI^k = \frac{\lambda_{max}^k - M^k}{M^k - 1}, \tag{7}$$

where: λ_{max}– own maximum value number of compared objects n, $\lambda_{max} = n$.

$$CR^k = \frac{CI^k}{RI(M^k)}, \tag{8}$$

where: $RI(M^k)$ – the value of Random consistency index for matrix of size M^k.

Step 4. From the group of pairwise comparison matrices obtained in the second step, a set of the local priorities vectors that reflect the relative influence of the plurality of elements relative to the element of the higher levels is formed. There are several methods for calculating the values of priorities vectors based on the matrix of pairwise comparisons: eigenvalue method, a geometric mean, an approximate method, the least squares, the weighted least squares, logarithmic least squares, mean of the normalised values etc. Priority assessment for the elements of the hierarchy structure is made in stages for each next level of the hierarchy.

As the result of this step we got the priority matrix B $\{B^0, B^1,...,B^K\}$, where B^0 - the priority vector for quality criteria of UPTS service calculated on the basis of the pairwise comparison matrix H^0 and B^k – the priority vector for quality indicators related to κ-th quality criteria and calculated on the basis of the matrix H^k, where κ=1..K. The element of the matrix B^k – b^k_j is the value of local priority of the indicator p^k_j.

Step 5. The final weights values for the quality indicators are obtained by the multiplication of the values of priority vector B^k to the appropriate priority value of the vector B^0:

$$w_j^k = b_j^k b_K^0, \tag{10}$$

where:

- w^k_j – the value of the weight coefficient for quality indicator j, which refer to the criterion k,
- b^k_j – the value of the priority vector B^k for the indicator p^k_j,
- b^0_k – the value of the priority vector B^0 for the criterion k.

So, the vector of the weight coefficients has the following form:

$$W = \{B^1 b_1^0, B^2 b_2^0, \dots, B^K b_K^0\}. \tag{11}$$

Due to the fact that the quality indicators in the constructed hierarchy structure are assigned to the corresponding quality criteria, rewrite the equation for calculating the UPTQI values for each city *i* as follows:

$$UPTQI_i = \sum_{k=1}^{K} \sum_{j=1}^{M^k} x_{ij}^k w_j^k. \qquad (12)$$

Step 6. The homogeneity of the throughout hierarchy structure is estimated by summing of all the levels given by weighting the 1st hierarchical level. The consistency of the hierarchy structure is satisfactory for values of $CR \leq 0.1$. Otherwise, the quality of the judgments should be improved by returning to the stage number two.

- **Aggregation**

At that stage, the UPTQI value by Equation 1 for all cities is calculated. As an aggregation method, the linear aggregation method is recommended for UPTQI estimation.

- **Uncertainty and sensitivity analysis**

The methodology of UPTQI construction entails a number of stages. In each stage, different choices need to be made. The purpose of an uncertainty and a sensitivity analysis is to check the extent of uncertainty created by the choice of each method vis-à-vis another in relation to the total uncertainty of the index. There are focused on three main points: set of quality indicators, imputation of missing data methods, weighting schemes.

The impact of changing one assumption was analysed while others remained the same, and the impact of joint changes was examined. For a single assumption, the following criteria can be used:

- the Person's correlation coefficient for UPTQI values,
- the Spearman's correlation coefficient for R (rank of city) values,
- the sum of squared deviations of UPTQI values.

The analysis is conducted as a single Monte Carlo experiment, e.g. by eliminating all uncertainty sources simultaneously to capture all possible synergy effects among uncertain input factors. This involves the use of triggers, e.g. the use of uncertain input factors to decide which methods to adopt. The adopted procedure of this approach has four steps:

Step 1. Assign a probability distribution function to each input factor F_i, where i=1, 2, 3. The first input factor, F_1 is used for the selection of the editing scheme:

F_1	Missing data imputation
1	unconditional mean imputation
2	imputation by simple random sampling
3	clustering-based imputation
4	K- nearest-neighbour imputation
5	imputation by predictive mean matching
6	Expectation-Maximization algorithm

The second input factor F_2 is the trigger to select the weighting method:

F_2	Weighting
1	Equal Weighting
2	Principal Components analysis
3	Benefit of the doubt approach
4	AHP approach

Uncertain factor F_3 is generated to select which quality indicator should be omitted:

F_3	Excluded quality indicator
0	All quality indicators are used
1	Excluding of the first quality indicator
…	…
M	Excluding of the M-th quality indicator

F_1, F_2 and F_3 are discrete random variables. In practice, they are generated by drawing a random number.

Step 2. Generate randomly N combinations of independent input factors F^l, l =1,2,...,N (a set $F^l = F_1^l, F_2^l, F_3^l$ of input factors is called a sample). The generation of samples can be performed using simple random sampling.

Step 3. For each sample l, exclude one quality indicator, select an imputation missing data method and weighting scheme on the base of F_1, F_2 and F_3.

Step 4. Evaluate the output values Y^l, where Y^l is the value of the $UPTQI_c^l$ or R_c^l for each city.

Step 5. Close the loop over l, and analyse the resulting output vectors $UPTQI_c^l$ and R_c^l, with l = 1,...,N. The sequence of $UPTQI_c^l$ and R_c^l gives the probability distribution function of the output Y. The characteristics of this probability distribution function, such as the variance and higher order moments, can be estimated with an arbitrary level of precision that is related to the size of the simulation N.

The results of the robustness analysis can be reported as city rankings with their related uncertainty bounds, which are due to the uncertainties at play. This would enable communicating to the user the plausible range of the UPTQI values for each city.

- **Result interpretation and visualization**

This stage includes the use of various methods for presentation of results, presentation of UPTQI values for cities in comparison with other related data, and an explanation of relative importance of UPTS service quality indicators. Data visualisation should receive proper attention, given that the visualisation can influence on interpretability of results. The purpose of this phase is to determine a set of presentation tools for the targeted audience, the selection the visualisation technique which communicates the most information and the presentation the UPTQI results in clear and accurate manner.

As a tool for visualization of UPTQI values and ranks for cities, a WEB-application has been developed within the framework of this work. The application performs the main functions as follows: storing the quality indicator values of public transport system for various cities; calculation of UPTQI values and ranks for cities; presentation of quality indicator values, UPTQI and ranks of cities in a tabular format and simple bar charts; import and export of data to other data formats.

10.3. The approbation of proposed methodology for UPTQI estimation

The initial data. For proposed methodology approbation, the data from the database EUROSTAT and the group of the cities with the most set of the indicators values have been used. Eight quality indicators are used from 21 founded in data base EUROSTA. The list of used quality indicators distributed over UPTS service quality components shown in Table 2.

Table 2.

List of UPTS quality indicators (from EUROSTAT)

Components of UPTS quality	Full name of indicator	Code
Availability	Proportion of journeys to work by public transport (rail, metro, bus, tram)	x1
	Length of public transport network / land area	x2
	Proportion of the area used for transport (road, rail, air, ports)	x3
Accessibility	Number of stops of public transport per km^2	x4
	Cost of a monthly ticket for public transport (for 5-10 km)	x5
	Number of stops of public transport per 1000 population	x6
	Number of stops per 1 km of public transport network	x7
Environment	Proportion of public transport network on fixed infrastructure /Proportion of public transport network on flexible routes	x8

To develop UPTQI, the data describing UPTS in 62 European cities were used with respect to 2003-2006 moments of time, from them: 37 German cities (without missing data) and 25 other European cities (basically capitals, 3 from them don't have missing data and 22 with missing data in quality indicators values, but no more than 3 missing values). The total number of missed values is 6.85% from the total number of values.

- **UPTQI estimation for the cities not having any missing data in quality indicator values**

Firstly, the UPTQI values were calculated for 37 German cities which do not have any missed values of quality indicator as according to the data obtained from 2002 – 2006. For the calculation of weight coefficient, three methods will be applied: PCA, BOD, and EW. Three UPTQI values – $UPTQI_{PCA}$, $UPTQI_{BOD}$ and $UPTQI_{EW}$ – have been obtained with respect to each city. The normalised UPTQI values and the respective rating of a number of cities are presented in Figure 8. Cities are arranged in order of decreasing of normalised UPTQI value calculated by PCA from Dusseldorf (1) to Bielefeld.

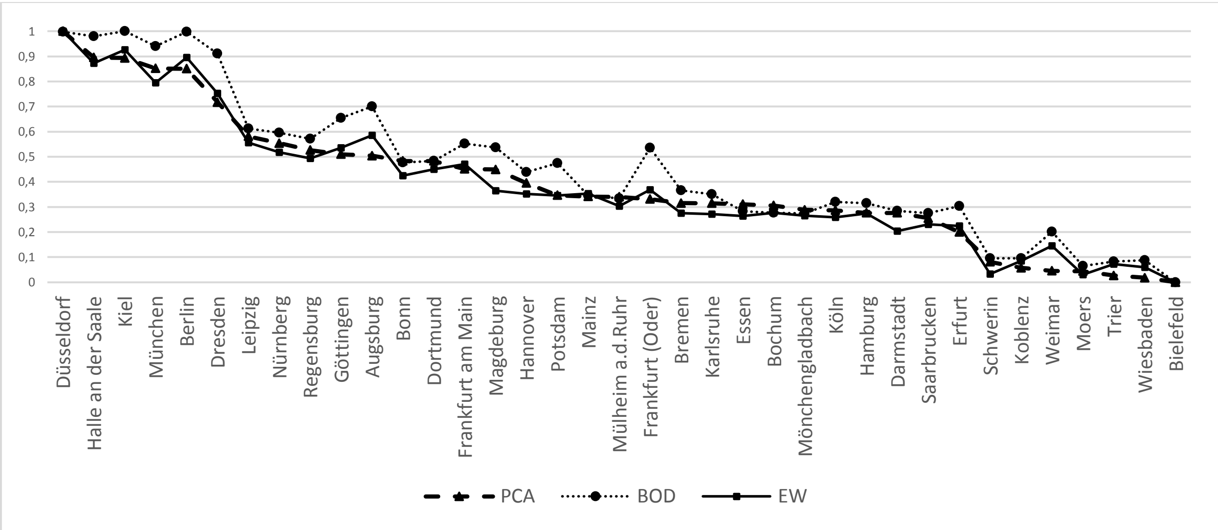

Figure 8. Values of UPTQI of 37 Germany cities

Analysing the results of calculating the three indicator alternatives, we can point out that the same cities are ranking top 10 except for Augsburg that has fallen out of the top ten ratings according to the index $UPTQI_{PCA}$; in terms of the other indices, however, the city remains at the 7th position. The least value $UPTQI_{PCA}$ has been achieved by the city of Bielefeld. At that, Bielefeld is ranking last also in terms of $UPTQI_{BOD}$ and $UPTQI_{EW}$. At that, the largest difference in ranks pertains to the city of Frankfurt (Oder).

- **The analysis of the UPTQI values changes in the time**

For the analysis of the UPTQI score changes in the time we will calculate its values for 37 cities according to 1999-2002 (*t1*) and will compare with calculated values for the data 2003-

2006 (*t2*). In the data at *t1* moment of time there are missing data for a set of variable 11 cities that makes about 7% from total quality indicators values. For imputation of the missing data has been used unconditional mean method. For calculation of the weights values considered methods also are used: PCA, BOD and EW. The weights coefficients values calculated by method PCA for two moments of time are presented in Table 3.

Table 3.

Weights values on the basis PCA model for two time moments

Time	w1	w2	w3	w4	w5	w6	w7	w8
t1	0.118	0.154	**0.079**	**0.104**	0.150	**0.114**	0.136	0.144
t2	0.105	0.140	**0.122**	**0.135**	0.148	**0.086**	0.110	0.155

The greatest changes of the weights values for two moments of time are observed for variables x3 (Proportion of the area used for transport (road, rail, air, ports), x4 (Number of stops of public transport per km^2) and x6 (Number of stops of public transport per 1000 pop.) It is obvious that the increase in weight for variables x3 and x4 is connected with increasing requirements of passengers to quality of services of public transport from the point of view of fuller covering network and approach of stops to attraction places. Also, it is important from the inerrability of urban public transport point of view. In Figure 9 are presented ranks for cities for two moments of time. Cities ordered by their UPTQIPCA (t1) position, ranking from 1 (for Dusseldorf) to 37 (for Bielefeld).

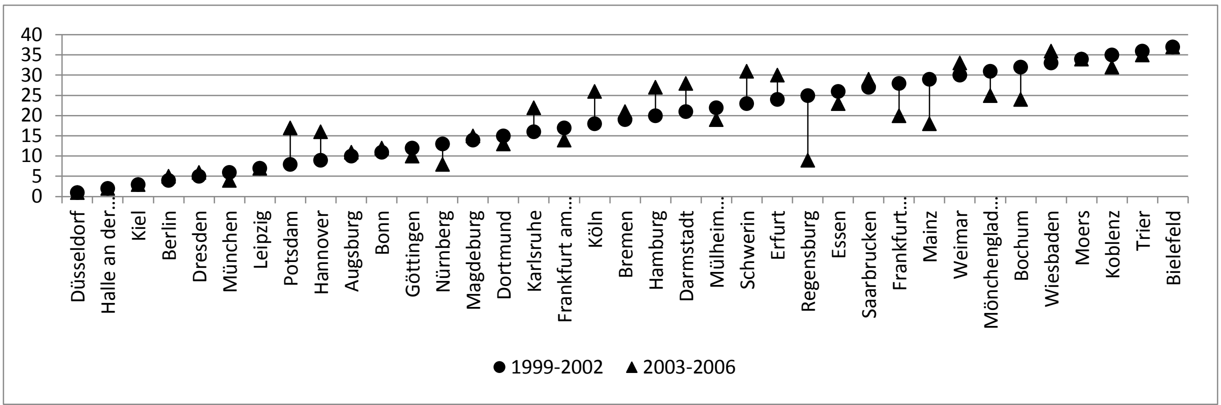

Figure 9. German cities ranks in two moments of time (PCA-methods for weights estimation)

- **Investigation of the influence of the missing data imputation methods to the UPTQI value**

To estimate the influence of methods of missing data imputation on the value of the quality index the following procedure has been applied based on the algorithm of the choice of missing data imputation method.

The input data: quality indicator values for 37 German cities (without missing data).

In random manner, 5% of the quality indicator values were removed from the data in the first case, 10% - in the second case, and 15% - in the third case. In each case, 10 runs of data skips-generating procedure were performed, implying the missing imputation by using the following six methods:

- unconditional mean imputation;
- imputation by simple random sampling;
- clustering-based imputation;
- K- nearest-neighbour imputation (k-NN);
- imputation by predictive mean matching (PMM);
- Expectation-Maximization algorithm (EM).

As a result, 48 values of UPTQI were obtained for each of the three cases, for each method of missing data imputation and for two methods of weight coefficient estimation. $UPTQI_{origBOD}$, $UPTQI_{origPCA}$, $R_{origBOD}$ and $R_{origPCA}$ were also received for the case implying without missing data.

Table 4 and Table 5 show the mean correlation ratio between the original values $UPTQI_{orig}$ and R_{orig} with the values received in the case implying skips in data and different count of skips, where the weighting factors are calculated by two methods - BOD and PCA. Table 6 shows the mean values of the SSD from the true value of the UPTQI. The largest value of correlation coefficient between the calculated $UPTQI$ and $UPTQI_{orig}$, also, between R and R_{orig} is observed for values obtained by the BOD method (the values are marked in Table 4 and Table 5).

Table 4.

The mean value of Pearson's correlation with originals $UPTQI_{orig}$

Method	**5% skips**		**10% skips**		**15% skips**	
	BOD	**PCA**	**BOD**	**PCA**	**BOD**	**PCA**
Random	0.943	0.936	0.911	0.892	0.866	0.829
Mean	0.970	0.960	**0.949**	0.933	**0.907**	0.875
Cluster	0.969	0.958	**0.949**	0.928	0.884	0.859
k-NN	0.976	0.961	**0.952**	0.931	**0.911**	0.877
PMM	**0.978**	0.959	0.934	0.913	0.894	0.887
EM	0.963	0.943	0.930	0.916	0.890	0.873

The best indices are observed when using the cluster-based, PMM and k-NN methods. Moreover, increasing the number of skips when using the cluster-based method the values of the indices deteriorate abruptly as compared to the other two methods; the reason is that the clusters are constructed with a lesser number of objects (without missing data) and, accordingly, the correctness of division by clusters arises some doubts. The k-NN method, in its turn, remains the best method when increasing the number of skips.

Table 5.

The mean value of Spearman's correlation with originals R_{orig}

Method	**5% skips**		**10% skips**		**15% skips**	
	BOD	**PCA**	**BOD**	**PCA**	**BOD**	**PCA**
Random	0.931	0.926	0.888	0.850	0.839	0.846
Mean	0.952	0.936	0.927	0.902	0.884	0.841
Cluster	0.951	0.938	0.929	0.908	0.850	0.813
k-NN	0.957	0.940	**0.933**	0.902	**0.889**	0.840
PMM	**0.964**	0.939	0.911	0.888	0.864	0.841
EM	0.941	0.917	0.907	0.883	0.853	0.824

Table 6.

The mean SSD for *UPTQIorig* and *UPTQI* what calculated with imputation

Method	**5% skips**		**10% skips**		**15% skips**	
	BOD	**PCA**	**BOD**	**PCA**	**BOD**	**PCA**
Random	0.406	0.425	0.679	0.655	1.090	1.066
Mean	0.211	0.254	0.356	0.427	0.659	0.731
Cluster	0.226	0.266	0.345	0.434	0.808	0.876
k-NN	0.176	**0.247**	**0.310**	**0.408**	**0.571**	0.662
PMM	**0.169**	0.280	0.446	0.530	0.659	**0.588**
EM	0.247	0.339	0.467	0.514	0.708	0.672

Furthermore, we have simulated skips in data proportionally the missing values in the full dataset. As in the previous cases the rank city values and UPTQI values closer to the original when the weights are calculated with BOD method and missing data is substituted by k-NN method (the Pearson's correlation mean value of 10 runs is 0.97, the Spearman's correlation value - 0.95). Moreover, the least value of SDD when skips are substituted by k-NN method (0.2) with low value of variation of 10 runs (0.004).

So, for our dataset we will use the BOD approach for calculating the weighting coefficients as the least sensitive to skips in data and k-NN method for missing data imputation.

For stability analysis, let us compare UPTQI values to the rankings of 37 German cities yielded with and without using data of other cities. Figure 10 shows the rankings of 37 German cities calculated in both cases (R_{37} and $R_{62->37}$).

The high value of the correlation ratio between normalised *UPTQI* values (the value of Pearson's correlation 0.94) and the rankings yielded for 37 German cities – both with and without other European cities included (the value of Spearman's correlation - 0.92) attest to the stability of the yielded results.

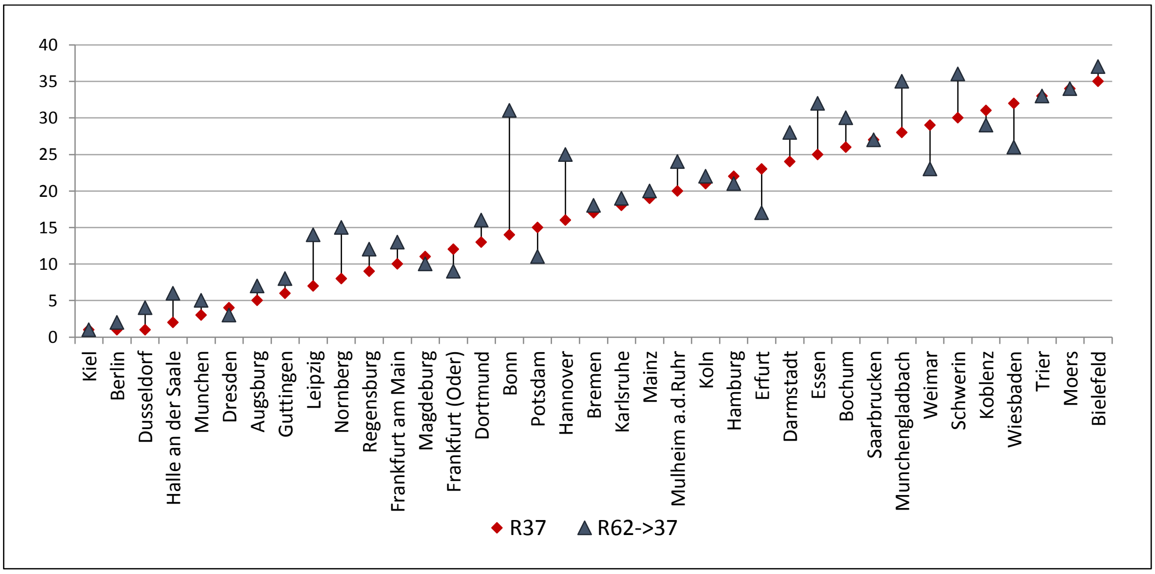

Figure 10. The ranks of 37 German cities with and without data of other cities

- **Analysing the influence of methods for weight coefficient estimation upon UPTQI value and calculating UPTQI value for all cities**

Because in case of BOD method the weight values are calculated for each city, the weight coefficients values obtained by AHP and PCA methods were compared only. Figure 11 shows the values of weight coefficients.

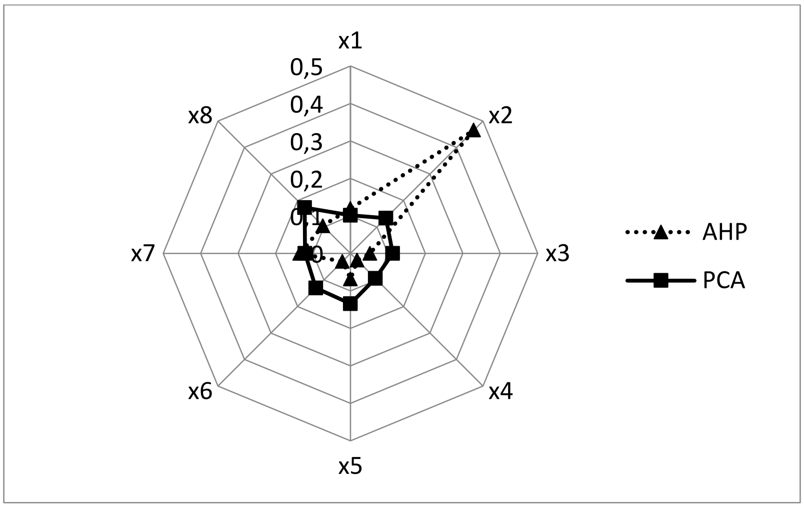

Figure 11. The values of weigh coefficients obtained by the AHP and PCA methods

Proportion of length of public transport network to the land area is defined by experts (AHP method) as the most important indicator of the quality of the UPTS service from the considered indicators, the weighting coefficient value - 0.465.

Approximately equal importance experts appointed to the indicators Proportion of journeys to work by public transport (rail, metro, bus, tram), Number of stops per 1 km of public transport network and Proportion of public transport network on fixed infrastructure / proportion of public transport network on flexible routes; the lowest importance to the indicators Number of stops of public transport per km^2 and Number of stops of public transport per 1000 pop. The values of weighting coefficients obtained by AHP differ from the weights obtained by the PCA. The high difference is observed in the values for Length of public transport network / land area (0.465). The highest value, 0.173, was obtained by PCA for Proportion of public transport network on fixed infrastructure/Proportion of public transport network on flexible routes, which reflects the impact on the environment. The weighting value derived by the AHP for this indicator is 0.105 and this indicator is only the fourth by importance.

The UPTQI values for 62 European cities, calculated using three methods: AHP, BOD and PCA are shown in Figure 12. Cities are arranged in order of decreasing of UPTQI value calculated by AHP from Helsinki (1) to Trier (0).

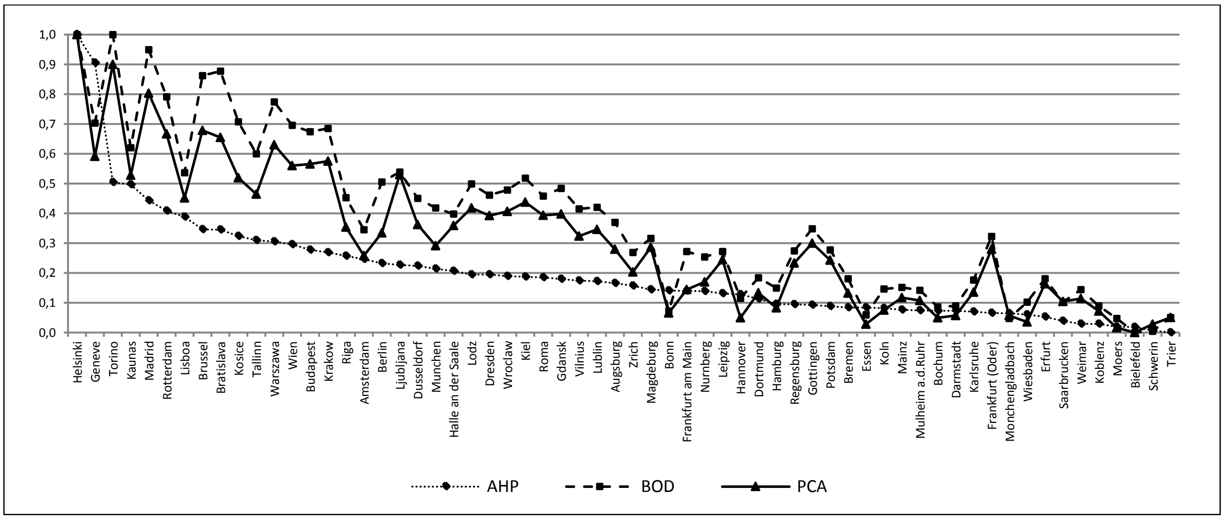

Figure 12. Values of UPTQI for 62 European cities with using AHP, BOD and PCA methods

Table 7 shows the correlation coefficients values between the UPTQI values and between the values of cities ranks obtained by different methods. For UPTQI values Pearson's correlation coefficients was used (above the main diagonal) and for cities' ranks - Spearman's correlation (below the main diagonal).

The values obtained by the BOD and PCA methods are very close, the correlation coefficient is close to 1 (0.988). The values obtained by the AHP have a greater difference, but the rate is still quite high - 0.813 and 0.834. This can be explained by the fact that the weights coefficients estimation based on AHP method ignores dependence (correlation) between the indicators, as opposed to methods based on statistical models.

Table 7.

The values of Pearson's correlation between UPTQI values and Spearman's correlation between ranks of cities

	AHP	BOD	PCA
AHP	1.000	0.813	0.834
BOD	0.928	1.000	0.988
PCA	0.909	0.987	1.000

The problems of AHP method for the UPTQI constructing includes the need in the large amounts of paired comparisons (N*(N-1)/2 pairs), with the full set of indicators characterizing UPTS service quality. This method is suitable for no more than for 10 indicators. But the strengths of the AHP method for the weighting coefficients estimation may be noted that the method relates to participatory technique and weights are easily explainable and it can be used to estimate the subjective indicators.

However, the main problem faced when estimating UPTS service quality is the problem of insufficiency of data – first of all, the data that can be yielded in process of transportation surveys – such as a travel survey for example.

The proposed approach can be used to estimate the UPTS service quality for cities, but for practical decision making it is need to use in the calculation the complete assessment quality indicators that characterise all components of UPTS service quality.

10.4. Public transport system service quality estimation for Riga city

This work provides the analysis of the question's status on the service quality of PT system in the city of Riga. According to the data from the Riga municipality (2015), the city territory is 303,996 km^2 and it is inhabited by 695539 tenants, there were 1778 streets with the total length of 1173 km and the total area 9.84 km^2. The main stakeholders on Riga public transport service market are the following: The Riga municipal Limited Liability Company *Rīgas Satiksme*, *Rīgas mikroautobusu Satiksme*, Joint Stock Company *Pasažieru vilciens* and Joint Stock Company *Rīgas starptautiskā autoosta*.

One of the biggest problems for the public transport service quality estimation consists in the lack of completeness of necessary data. As it is noted in chapter 1 of this thesis, all the data on quality service can be divided into 2 main groups – objective and subjective. Data on public transport of Riga are not complete neither in group objective, nor in group of subjective indicators.

Table 8 shows the main availability indicators values for UPTS of Riga (source „Rīgas satiksmes" for 2012).

Table 8.

Main availability indicators for UPTS of Riga

Indicator	All	Bus	Trolleybus	Tram
Run (mileage) within the route network (kilometres for tram), in thousand km. (tech run exclusive)	41 634	24 629	12 258	4 746
Route length, in km.	1 259.88	898.08 109.05(at night)	161.53	91.22
Number of routes (as of 2012 year-end)	90	62 9 (at night)	19	9
Number of vehicles servicing the route, maximum number of hours (as of 2012 year-end)		317 9 (at night)	199	66
Number of passengers carried, M.	141.37	64.45	46.23	30.69

Buses constitute the largest part of the Riga public transport network, with trolleybus being the next and tram holding the third place. The total number of passengers carried by *Rigas*

Satiksme in 2012 exceeded 141 M, while 150.1 M had been carried in 2013, thus, having reached the 9.4% – increase year-on-year.

This work considers opportunities and problems to estimate all eight groups of quality indicators. The group of indicators, belonging to information groups investigated in more detail: the accessibility of information within the Riga public transport system. To do that, evaluated the following individually:

- general information accessibility: the data describing existence, accessibility, sources of information, travel time, customer service, convenience, safety, and environmental impact;
- information furnished under normal conditions: Street references, embarkation / disembarkation point identification, vehicle signage, travel route data, time data, fare data and the data describing forms of a travel voucher;
- information furnished under abnormal conditions: data on current/predicted status of network, on alternative possibilities, on compensations/appeals, on suggestions and complaints, and on lost property;

with distribution by location (in the Internet, by phone, on stops, in a terminal, in a vehicle, in mass media etc.) and by transport mode (tram, trolleybus, bus, minibus, train, intercity bus). If some information of the above-stated kind is available, 1 (one) point is counted; if there is total lack of such information – 0 (zero) points; if information exists but is not complete – 0.5 points is counted. We will define the general level of accessibility as the scored points/maximum possible point number ratio. Therefore, the information availability value fluctuates within the interval [0;1], where 0 means lack of availability and 1 – the highest availability level. The overall evaluation of the Riga public transport availability data constitutes 0.74; it can be seen from Table 9 how it looks like if split by kinds of information and by transport modes. It can be seen that the worst situation in Riga refers to driving information availability under normal conditions, while the best situation is in the field of general information availability. The largest available amount of information concerns trolleybuses, trams, and trains; the least amount of the respective information concerns minibuses.

According to the obtained data, one can drive to the conclusion that special priority should be given to the improvement of driving information availability under normal conditions – especially with regard to minibuses and intercity buses. Moreover, one should focus on the improvement of driving information availability in an emergency by furnishing vehicles and transport stops with the corresponding equipment.

Table 9.

Information availability estimation about public transport in Riga by modes

Type of information	Tram	Trolleybus	Bus	Minibus	Train	Intercity bus	Total availability
General information	0.93	0.93	0.8	0.52	0.84	0.67	**0.78**
Travel information normal conditions	0.7	0.75	0.73	0.57	0.77	0.57	**0.68**
Travel information abnormal conditions	0.82	0.85	0.81	0.48	0.84	0.82	**0.77**
Total	**0.82**	**0.84**	**0.78**	**0.52**	**0.82**	**0.69**	**0.74**

This work carries out the analysis of the transport surveys realized in Latvia and in Riga. It showed that such surveys are conducted not regularly. There are realized by different instances, using various methodologies. Data are not stored centralized and there is no opportunity to unite them and for analysis.

Several transport surveys, which partly or fully gathered information about usage of public transport by city tenants, were held in Latvia and Riga. In the Table 10 the comparison of surveys and data sources is given.

Table 10

Transport surveys in Latvia

Name of survey	Period	Information about PTS[1]		
		Supply data	Demand data	Customer satisfaction
Optimization of public transport	5 – 29 March 2002	-	++	+
Riga modern tramway project	17-18 September 2002	+	++	-
Passenger mobility survey in Latvia in 2003	19 May – 5 June 2003	-	+	-
Time use survey in Latvia	Feb. – Aug., Oct.- Nov. 2003	-	-	-
Database Eurostat	2003, 2006	+	+	+
Riga development plan for the years 2006-2018	Autumn 2004	++	++	-
Passenger mobility survey in Latvia in 2008	29 Sept. - 14 Nov. 2008	-	++	-
Customer satisfaction	Spring 2011	-	--	++

Two Latvian population mobility surveys of were held in years 2003 and 2008: *Passenger mobility survey* in Latvia in 2003 and in 2008. The access to this surveys data is restricted; the authors have access to a generalized report only and thus have no chance of obtaining any data on public transport usage by citizens of Riga. Moreover, there is no opportunity of comparing the results of the survey, since various methodologies had been used in process of the surveys.

[1] - data was not gathered, + partly gathered, ++ information was fully gathered.

The only thing that can be mentioned is that, according to the results of the survey-2003, 53% of the Riga citizens used public transport to make work trips.

The results of "*Time-use survey in Latvia in 2003"* (Central Statistical Bureau of Latvia, 2004) have shown that Riga city population spend in average 10.7 hours per week for their trips. Not any other information about population trips was gathered during this survey.

In 2011, "*Rigas satiksme"* had conducted a Customer satisfaction survey. According to the results of the survey, 81% of the Riga residents are satisfied with the public transport services in the city. Unfortunately, the author had no information on the methodology of conducting that survey by the time this thesis was written.

Also in the work attempt to apply the methodology of UPTQI estimation for Riga city. Let's consider the UPTQI value for Riga public transport system, which has been calculated with 61 European cities and compare the obtained UPTQI value of the Riga City with the indicator values of other cities that have about the same population and population density as the city of Riga. Those cities are: Krakow, Lodz, Wroclaw and Frankfurt am Main. Further, let us compare the Riga City UPTQI values with that of the neighbouring countries' capitals such as Tallinn and Vilnius (Table 11). For comparison, eight quality indicator values corresponding to seven countries are shown in Table 11 also.

Table 11

Quality indicators values, UPTQI values and ranks for Riga and some others cities (by BOD)

Rank	Cities	x1	x2	x3	x4	x5	x6	x7	x8	UPTQI
10	Krakow		168.6	9.9	7.1	18.8	3.1	4.2	0.18	0.69
13	Tallinn	49.8	479.8		5.8	23.3	2.2	1.2	0.05	0.60
18	Lodz		203.1	11.8	5.8	17.5	2.2	2.8	0.29	0.50
20	Wroclaw		203.9	9.8	5.1	12.4	2.3	2.5	0.16	0.48
23	**Riga**		**553.8**	**14.9**	**4.7**	**27.4**	**1.9**	**0.8**	**0.07**	**0.45**
27	Vilnius	33.9	238.7	10	2.9	14.5	2	1.2	0.01	0.42
36	Frankfurt am Main	38.5	271	17.7	3.3	62.3	1.3	1.2	0.37	0.27

As is obvious from the proposed data, the Riga city has no value after the indicator *x1* (Proportion of journeys to work by public transport (rail, metro, bus, and tram)). Let us replace the missing values of the variable *x1* for the city of Riga with the estimated quantity - 33.80.

If we compare the obtained UPTQI for the Riga city with that of the neighbouring countries' capitals – Tallinn and Vilnius, we will see that Riga is ranking in the middle among the capitals of the three Baltic States, while Tallinn is ranking first (the 13th line in the rating for 62 countries) with the index 0.60; the rating of Tallinn is by seven lines higher than that of the Riga city. The cities are ranked in descending order according to UPTQI values. Four cities out of the seven proposed ones lack values of *x1* variable (the share of work trips by using public transport). This is entailed by some drawbacks of national transport systems observed in these cities, whereas in German cities and in other well-developed countries of Europe, this is the main source of data for the estimation of urban transport system.

As against the indices corresponding to the proposed seven cities, Riga has sufficiently large values of the variable x2 (length of public transport network/territory acreage) and x3 (part of the territory used for transport operation); this attests to a well-developed urban infrastructure. Riga is ranking 5th among the proposed seven cities in terms of the variable x8 (the share of public transportation network with a fixed infrastructure/the share of public transportation network with flexible routes), - where the variable x8 characterizes the environmental effect (since the fixed-route transport uses some alternative kinds of fuel (electricity for example). Variables: x4 (the number of public transport stops as per 1 km^2), x6 (the number of stops as per 1000 city residents) and x7 (the number of stops x7 (the number of stops as per 1 km of public transport route) – characterise UPTS accessibility from the public transport user – passenger standpoint, and, in terms of the above-stated variables, the city of Riga holds the next-to-last and the last line (Figure 13).

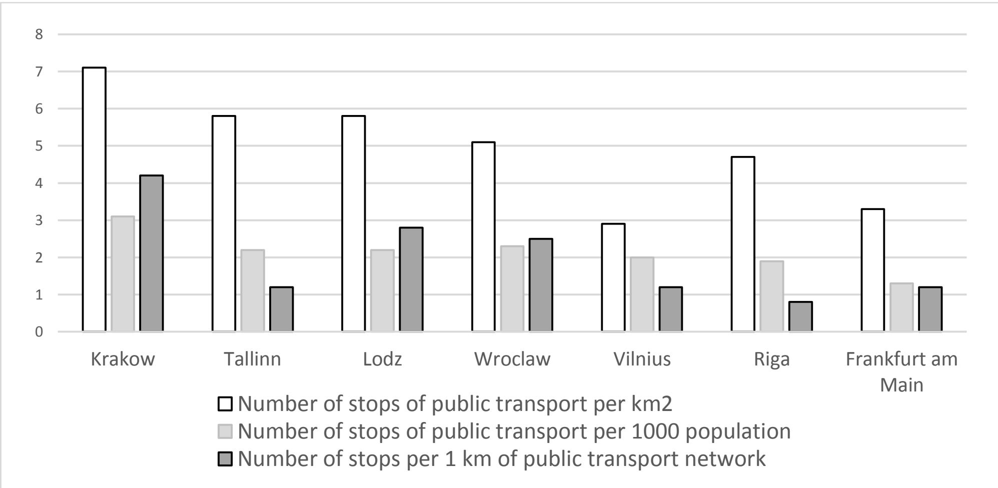

Figure 13. Number of public transport stops in some cities

- **Recommendation**

In Latvia and Riga, there are no programs to evaluate the quality of urban public transport and no national programs on conduction of transport surveys. All transport surveys in Riga are being conducted with a certain object and concrete goals and they are not systematically. And the main problem that these surveys do not reveal trends in the quality of service UPTS, and therefore does not allow to manage on the basis of information about perceived quality. To solve the task of increasing the level of public transport usage in Riga, a permanent systematic monitoring of UPTS performance and quality should be introduced (Figure 14).

Latvia as a country lacks its own quality standard of public transport service. The public transport passengers' service standards are determined by Cabinet-issued regulations. Therefore, the first thing to be done is the development of a Latvian public transport service quality standard based on the European standard EN13816, taking into account some national peculiarities of transport system infrastructure, transport policy and economy. The standard should include a set of indicators and its definition and should be developed in partnership with researchers, transport operators and government. Secondly, the UPTS quality evaluation concept should be worked out based on the standard developed. The concept should take the experience of other European countries and the respective projects into consideration, and should be able to answer the following questions: how indicators are measured? How are the observations made, and who makes them? How often should observations be performed? What kind of methods should be used for data collection? - etc.

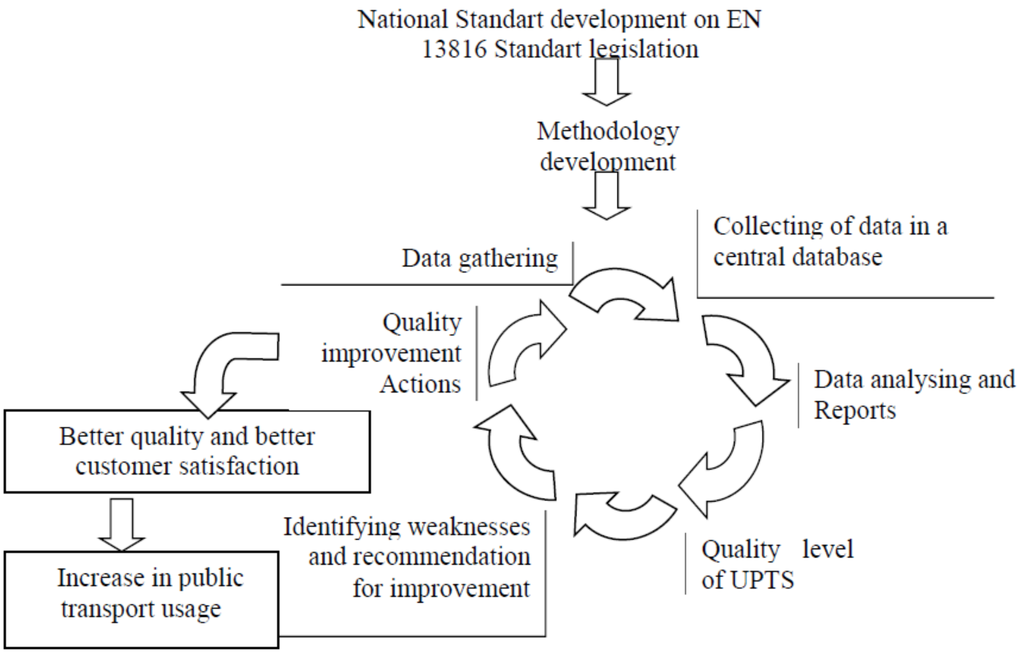

Figure 14. Loop for monitoring of UPTS quality

The UPTS demand and customer satisfaction data can be collected only through a mechanism of transport survey. The following four kinds of survey are hereby suggested which should be conducted in Riga at some regular intervals: public transport system inventory survey, household travel survey, customer satisfaction survey, and passenger counting.

11. RESEARCH RESULTS AND CONCLUSIONS

The work is dedicated to city public transport system quality estimation from user's point of view. The relevance of the work is determined by:

- lack of a unified consistent approach to UPTS quality estimation in Europe;
- lack of UPTS service quality estimation program in Latvia;
- the complexity of drawing a qualitative comparison between the actual quality of public transport system in different cities and countries on the basis of the multivariate set of data;
- lack of a consistent data collection technique based on UPTS service quality indicators.

The existing methods for service quality estimation have been analysed. To estimate the service quality of urban public transport system, the idea of benchmarking and the composite indicator constructing theory was combined.

The composite indicator-based methodology for constructing the UPTS service quality index (UPTQI) has been developed.

A comparative review of UPTS service quality indicators has been conducted as a result of which have been proposed:

- a classification of UPTS service quality indicators was suggested;
- requirements to quality indicators characterizing UPTS service quality from user's viewpoint, which have to be included in UPTQI, have been formulated;
- list of UPTS service quality indicators grouped by eight quality components and containing 51 indicators, has been compiled.

The suggested methodology contains: recommendations for organizing transport surveys to obtain UPTS service quality data; some examples of procedures and tools for Public Transport system inventory survey and Household Travel survey; requirements to the database for storing values of UPTS service quality indicators and the database model.

The data insufficiency problem gives rise to the data missing problem. The UPTQI constructing methodology suggests the algorithm for selection of missing values imputation method fit for the data available.

A comparative analysis of weight coefficient estimation methods, reflecting each quality indicator's contribution into UPTQI, is performed: the classification of methods is presented and their main advantages and drawbacks are identified; the influence of the selected weight coefficient estimation method upon UPTQI values is analysed.

As an experiment, the UPTQI constructing methodology was applied for UPTQI estimation with respect to 62 European cities; this enabled one to analyse the influence of the selected methods for weight coefficient estimation and missing data imputation upon UPTQI.

An analysis of the availability of Riga UPTS service quality data has been performed. This work formulates recommendations for the organization of transport surveys for monitoring of UPTS service.

The proposed approach can be used to estimate the UPTS service quality for cities, but for practical decision making it is need to use the complete set of quality indicators that characterise all components of UPTS service quality.

The survey findings were used in academic activities run by the Transport and Communication Institute when the education course "Traffic flow data collection and processing" was run and the practice according to the curriculum "Business administration on transport" was covered; moreover, the survey findings were used within the framework of the following projects: "Analysis of pedestrian and transport flows for pedestrian street creation in Riga city", 2011; "Freight traffic flow research and rerouting from Riga city centre", 2014; "Traffic flow study and modelling of the Hanzas-Sporta-Skanstes-Vesetas streets area", 2015.

The future research plans call for the following:

- to continue the research in the field of weight coefficients estimation, for example, estimate the possibility to combine methods based on statistical analysis and AHP; and in developing the methodology for estimation of various subjective quality indicators (on the basis of customer satisfaction survey) and objective quality indicators (based on records from testifiers of e-ticket, and on GPS signals with a mobile application);
- to develop a method of data collection for some quality indicators on transport system macromodel.

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