Methodology for the Multi-Objective Analysis of Data Sets in Freight Delivery

Dale Dzemydiene, Aurelija Burinskiene, Arunas Miliauskas, Kristina Ciziuniene

***Abstract*—**Data flow and the purpose of reporting the data are different and dependent on business needs. Different parameters are reported and transferred regularly during freight delivery. This business practices form the dataset constructed for each time point and contain all required information for freight moving decisions. As a significant amount of these data is used for various purposes, an integrating methodological approach must be developed to respond to the indicated problem. The proposed methodology contains several steps: (1) collecting context data sets and data validation; (2) multi-objective analysis for optimizing freight transfer services. For data validation, the study involves Grubbs outliers analysis, particularly for data cleaning and the identification of statistical significance of data reporting event cases. The Grubbs test is often used as it measures one external value at a time exceeding the boundaries of standard normal distribution. In the study area, the test was not widely applied by authors, except when the Grubbs test for outlier detection was used to identify outsiders in fuel consumption data. In the study, the authors applied the method with a confidence level of 99%. For the multi-objective analysis, the authors would like to select the forms of construction of the genetic algorithms, which have more possibilities to extract the best solution. For freight delivery management, the schemas of genetic algorithms' structure are used as a more effective technique. Due to that, the adaptable genetic algorithm is applied for the description of choosing process of the effective transportation corridor. In this study, the multi-objective genetic algorithm methods are used to optimize the data evaluation and select the appropriate transport corridor. The authors suggest a methodology for the multi-objective analysis, which evaluates collected context data sets and uses this evaluation to determine a delivery corridor for freight transfer service in the multi-modal transportation network. In the multi-objective analysis, authors include safety components, the number of accidents a year, and freight delivery time in the multi-modal transportation network. The proposed methodology has practical value in the management of multi-modal transportation processes.

***Keywords*—**Multi-objective decision support, analysis, data validation, freight delivery, multi-modal transportation, genetic programming methods.

D. Dzemydiene is Prof. Dr. at Vilnius Gediminas Technical University, Faculty of Business Management, Sauletekio av. 11, Vilnius LT-10221, Lithuania and Vilnius University, Institute of Data Science and Digital Technologies, Akademijos str. 4, Vilnius LT-08412, Lithuania (e-mail: dale.dzemydiene@mif.vu.lt).

A. Burinskiene is Assoc. Prof. Dr. at Vilnius Gediminas Technical University, Faculty of Business Management, Sauletekio av. 11, Vilnius LT-10221, Lithuania (corresponding author, phone: +370 686 03890; e-mail: aurelija.burinskiene@vilniustech.lt).

A. Miliauskas is specialist at Vilnius Gediminas Technical University, Faculty of Business Management, Sauletekio av. 11, Vilnius LT-10221, Lithuania (e-mail: arunas.miliauskas@vilniustech.lt).

K. Ciziuniene is Assoc. Prof. Dr., Vilnius Gediminas Technical University, Transport Engineering Faculty, Plytinės str. 27, Vilnius LT-10105, Lithuania (e-mail: kristina.ciuziuniene@vilniustech.lt).

I. INTRODUCTION

NOWADAYS, the large spectrum of innovative technologies are implemented in the management of multi-modal transportation of freights. Also, the European Union targets that more than 50% of innovative technologies' [1] implementations must be achieved by 2050. The corridors' networks are oriented for developing under more innovative and larger infrastructure and are supported by efforts, which have possibilities for consolidation of the achievements for high-efficiency, and low-emission of freight's transportation [1].

A large spectrum of context data sets by reporting freight positions typically needs to be merged, filtered to eliminate extraneous locations and noise or omit other inaccurate data. There are some studies, researching data validation topic. Carrion et al. removed inaccurate data indicating the time gaps or unrealistic velocities [2] to conduct a freight travel survey. Both Lin et al. and Jackson et al. applied Kalmar filter - which recursively measures individual data points and smooths out noisy meanings [3], [4]. Greaves et al. and Broach et al. took the primitive approach – to screen and remove outsiders manually based on the best indications [5], [6]. Also, Kuppam et al. visually inspected the sample data for survey purposes [7]. To respond to these questions, the authors present the methodology for the multi-objective analysis, evaluate the context data sets, explore the possibilities of collecting historical data, and provide an approach for ranking and selecting a transport corridor for freight transfer. This process supports the needful services in the multi-modal transportation processes by choosing the best network. The paper focuses on three kinds of transportation as underground Transport by automobiles, railways, and water transport networks.

The paper is organized into sections. The review of methods applicable to multi-objective analysis in freight delivery is presented in the second section. The suggested methodology for the multi-objective analysis of context data sets in freight delivery is provided in the third section. The structure of methodology is provided in subsection *A* of Section III. The data inputs are presented in subsections *B, C* and *D*; the methods – at the subsections *E* and *F* and the outputs generated – are in the subsection *G*; the possible environment for methodology application is investigated at the subsection *H*. Finally, conclusions are presented in the fourth section.

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II. Review of Methods for Multi-Objective Analysis in Freight Delivery

A. Review of Methods Applied in Freight Delivery

Technical and organizational measures, including the formation of rational transport schemes, that allow transport to perform its functions efficiently at the lowest cost, become important. Many methods are known today that help to solve the problem of traffic distribution in the network. They can be simpler when linear mathematical models and more complex describe the problem - in nonlinear cases [8], [9].

Many methodologies are developed in recent days for its usability, complexity and, of course, the accuracy of the results [2]-[7]. One of those is the so-called multi-criteria. A lot of research is being done on container flow forecasting [8]-[13].

Among the more complex prediction methods, one can mention the prediction possibilities, which include a highly complex network of conditions with these magnitudes' scattering algorithms. Another very important and extremely complex approach uses three-time modules divided into three flow groups (import-export, coastal and transit volumes) [10]. There are three methods used to forecast container flows 1) classical decomposition forecasting method [11], 2) trigonometric regression forecasting method [12], 3) "Promethee I" method is used to evaluate the best alternative that combines and applies the ideas of the several methods: SAW (Simple Additive Weighting), AHP (Analytic Hierarchy Process), COPRAS (Complex Proportion Evaluation Method), TOPSIS (Technique for Order Preference by Similarity to an Ideal Solution), etc. [13].

Despite all the mathematical, multi-criteria and so on methods used in the transport sector, efforts are now being made to link all solutions and tools for information and intelligent transport systems that speed up processes.

Intelligent transport systems include architectures, systems and infrastructure that seek to ensure transport functionality, security, communication quality and the needs of users of this infrastructure. Many companies and institutions are interested in using this infrastructure. Many large companies have logistics departments and individual companies engaged only in logistics services and will be interested in joining this system. Several programs help flight operators and drivers of public transport services, commercial freight, long-distance, and city-to-city deliveries; for example, 1) vehicle and driver scheduling, an automatic compilation of travel reports; 2) selection of the optimal route for standard and non-standard (large dimensions) vehicles; 3) monitoring the location of goods during their transportation and their physical condition if they are perishable and dangerous products.

Some of the most common design solutions used in the transport sector are TelemArk, Actif, Artist's solutions, and the main technical solutions with Siemens and Telvent [14].

The evaluation of route optimization systems found that two are most used: static and dynamic route systems. And in the analysis of the shortest pathfinding algorithms, the finding the fastest route can be equated to finding the shortest path in a weighted directional graph. The vertices correspond to the intersections, the edges to the roads. The algorithms found for the shortest path use edge weights for calculations. If we replace this weight with a corresponding factor, the algorithm will calculate the shortest and fastest path. Good algorithms have already been developed to solve the shortest path algorithm, such as Dijkstra, Bellman-Ford, Floyd-Warshall, Johnson, Depth-First Search (DFS), Breadth-First search or BFS [14].

B. The Application of Genetic Algorithms in Freight Delivery

The freight delivery process is quite complex and costly. Usually, almost half of the logistics costs are spent on freight delivery. Sometimes, the application of traditional methods is too complex, and authors for the optimization include genetic algorithms (GA). Many of them use GA to minimize freight delivery costs and/or total travelling distance and/or the reduction of energy during delivery [15]. The problem itself is usually the multi-objective or single objective. In a multi-objective case, authors involve several constraints for searching the optimal solution. For example, Pierre et al. solve the problem, reducing costs and the number of vehicles [16]. Zhang et al. focus on relieving travel time and the constraints of vehicle capacity [17]. Kumar et al. used three constraints: time windows, truck capacity, and maximum route time required for cargo delivery [18]. Although the studies are quite recent, the number of papers, which use GAs for finding the solution in freight delivery, is quite low. The studies delivered are provided in Table I.

TABLE I
THE APPLICATION OF GAS FOR FREIGHT DELIVERY PROBLEM

	Description of freight delivery problem				
Studies	Multi-objective	Single objective			
		Multi-depot	Multi-period	Multi-vehicle types	Multi-time windows
[15]	X	X			
[16]	X				X
[17]				X	
[18]	X			X	X
[19]		X			
[20]					
[21]	X	X		X	X
[22]		X			
[23]	X	X			
[24]			X		

Following freight delivery activity, this article presents the methodology for multi-objective analysis covering transport corridor selection in the multi-modal transport network. The problem is specified as the extension of the vehicle routing problem (VRP) and follows the studies mentioned above in several aspects:

(1) The previous studies [15]-[24] focus on route improvement. However, the methodology presented in this study considers underground transportation network aspects and the selection of transport corridor among possible alternatives, where start and end locations of the

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freight delivery process are predefined in advanced.

(2) Authors [15], [18]-[20] use Euclidean distance for finding the best solution to the freight routing problem. However, the authors of this paper use the path-based length to describe the transportation corridor.

(3) The published studies [17], [18], [21] assume the total volume to be delivered in the single-mode case and the selection of vehicle, which is incapacitated. The authors in constructed methodology consider the multi-modal delivery when the freight is transferred by various transport modes such as land, water, and rail. The key difference between multi-modal and single-mode freight transport is access to more than one mode of transport on time in the delivery process, including the characteristics describing the mode changing.

(4) The transportation of freight could single-period and multi-period. However, authors [15]-[23] assume that freight transportation activity in a multi-modal transportation network is by nature multi-period.

(5) In previous studies [15], [19], [21]-[23], the authors include the multi-depot aspect, which is mainly used to consolidate different products. The proposed methodology also considers the temporal storage terminals as the underground transportation network elements, which could be required for reloading products from one transport mode to another or are used as customs tax declaration terminals.

In the next section, we suggest the application of the GA in provided methodology.

III. Methodology for the Multi-Objective Analysis of Context Data Sets in Freight Delivery

We suggest a methodology for the multi-objective analysis. It evaluates collected context data to select a transport corridor for freight transfer service in the multi-modal transportation network.

Multi-objective analysis has been applied in many science fields, including engineering, where it is necessary to make optimal decisions among trade-offs representing two or more goals that may contradict each other. For example, in engineering applications, the designer makes decisions between contradicting targets, covering maximum efficiency, reducing fuel consumption, and truck CO_2 emission. In those cases, authors suggest performing multi-objective analysis that reflects trade-offs between target functions.

In summary, the multi-objective analysis presented in this paper includes:

(a). Travel time reduction: Each transport corridor's transport time is calculated directly by dividing each path's length by its travel speed.

(b). Reducing transport risk: For calculating the transport risk, we are taking an accident in a year.

In the multi-objective analysis, authors include context data sets about the number of accidents a year, the number of delay cases a year, the number of fraud events a year, total freight delivery duration. Based on the multi-objective analysis, the number of transport corridors matching freight delivery direction is ranked in sequence order for the prevision of cargo transfer service.

The methodology consists of three layers:

1. The infrastructure for data input and implementation layer,
2. The context data analysis and methods application layer,
3. The generated output layer.

The methodology is presented in details below.

A. Structure

The proposed methodology contains several workflows: (1) collecting data sets and data validation; (2) multi-objective analysis to optimize freight transfer service. Contemporary methods and their implementations are used to support freight delivery management.

The first method included in the methodology is data validation method, i.e. Grubb's outlier detection method. This method is important for data cleaning and approximation. In a unique dataset, treatment is important for many reasons. First, extraneous indicators can significantly impact the multi-objective analysis results (e.g., lead to inappropriate multi-objective analysis and inaccurate predictions). Therefore, it is important to identify this before modeling and analyzing the data. For example, outsider detection is the most important step in creating a high-quality process. Second, it is often caused due to recording errors; some can represent interesting phenomena (e.g. severe weather cases). Third, outlier's inclusion can significantly reduce the performance of the multi-objective analysis.

The second method included a constructed setup optimization method, which uses context data set into multi-objective analysis aiming to rank transport corridors for freight transfer service and suggests the one that matches the optimization direction. For that GA is used. GA application is the best solution for a particular problem such as feature optimization or a combinatorial problem found when considering many possible solutions. Our application has a problem describing the data for finding the best potential transport corridor.

Grubb's outlier and GA methods are intricately connected. The data validation method uses known information, such as historical data and information collected from GIS, and after it, the data sets are used for the second method. The second method proposes the transport corridor solution and does not generate any data sets. Also, such a combination of methods is quite new in recent literature. Previous authors [25] have applied GAs for outlier's elimination but other algorithms for transportation corridor selection. These methods are included in the suggested methodology for the multi-objective analysis of context data sets in freight delivery.

B. Data Inputs

For the delivery of multi-objective analysis first step is the collection of data inputs. According to the complexity of freight delivery, we have to decompose data inputs into multi-partial composing elements. For inputs, we consider such elements:

1. Physical-technical characteristics of the multi-modal transportation network are taken into account.
2. The historical data describing each transport corridor's performance in the range of those corridors are used for consideration during the application of multi-objective optimization method.

Data Sources: By analogy, sophisticated technologies such as Bluetooth, Geographic information system, Global Positioning System, Cross-border sensors, and Wi-Fi are constantly producing detailed footprints about freight delivery status and road conditions in transport corridors. There a lot of context data records from transport operators as well can be used for the evaluation. Although, only average values from a previous historical period in freight transfer service are important.

C. Specification of Physical-Technical Characteristics of Multi-Modal Transportation Networks

For the specification of the network, physical and technical characteristics are important. The representation of the interaction of objects in roads of the automobile, rail and water transport means, are included in our consideration of multi-modal transportation network. The conceptual representation of provided designing schemas is developed by using Unified Modeling Language (UML). Such structures became the main parts for the provision of information for operative and analytical decisions under developing. As an illustration of the description of physical-technical transport networks of multi-modal transportation, the conceptual schema is presented in Fig. 1. Such physical-technical features participate later on in revealing alternative transport corridor for freight transfer service.

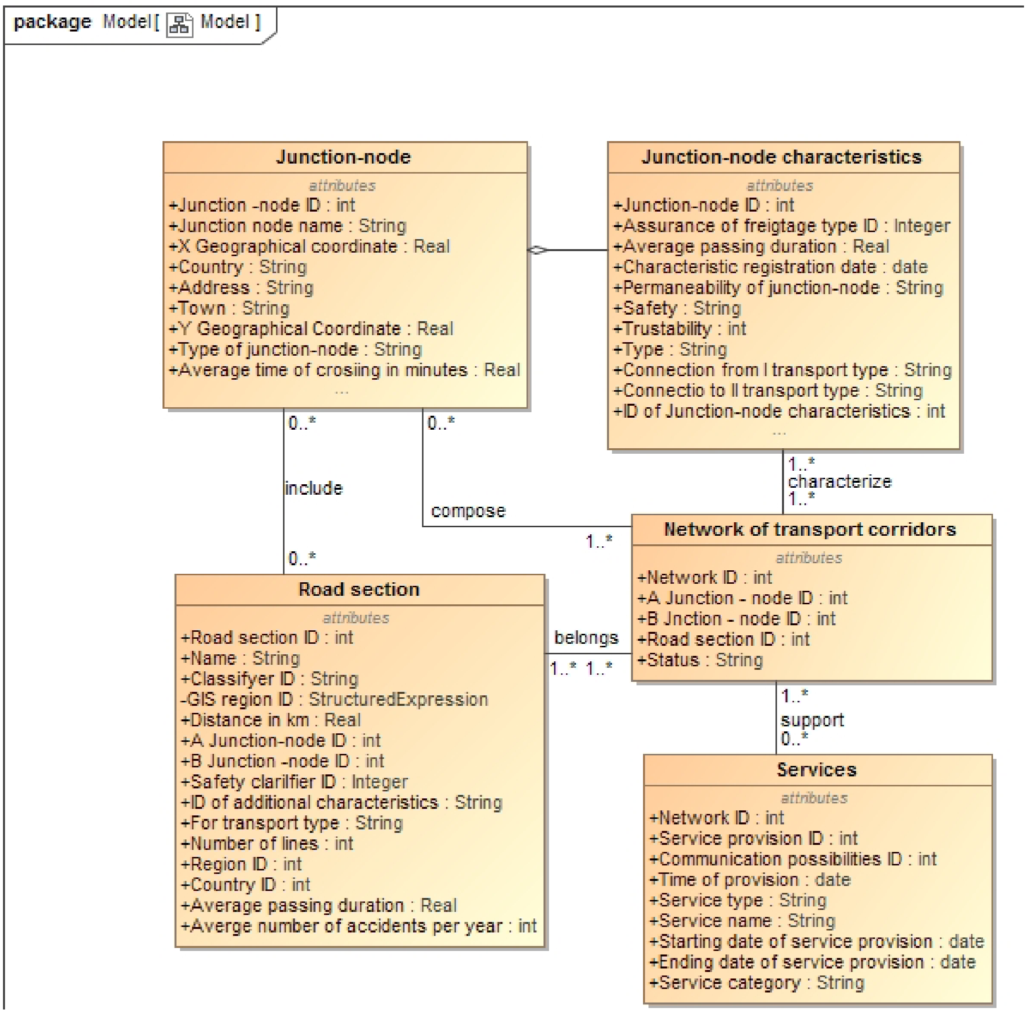

Fig. 1 Structure for evaluation of physical-technical characteristics of network roads for multi-modal transportation

Physical-technical characteristics are collected from geographic information system database, where it is possible.

D. Historical Data about the Performance of the Transport Corridor

Many parameters (like location, speed, direction, date, time, etc.) are regularly transferred during freight delivery. Such practices form the dataset which is constructed for each time

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point and contains all required information. This information presents historical data which are used for the decision concerning freight transferring.

For the evaluation of the performance of a transport corridor, historical data must be collected for decision making. Multi-modal-based transport corridor has time characteristics, which consider the time and the cost required to switch one mode to another.

One of the key features that distinguish the roadway from railway and water-way is time schedules. The timetables provide detailed information for each transport service on each type of network, i.e. the departure time at the departure terminal and the arrival time at the destination terminal.

For water-way transportation where delays are frequent, historical data about delays could be collected together with other data describing safety (Fig. 1) and the number of disturbances per year. Historical data also integrate speed and safety regulations for each modality and road type. The average speed in the transport corridor is the main component specifying the length of freight delivery. Historical data may also describe the average fuel consumption norm for road transport, and cost components such as distance, time, or service. For example, costs for taking scheduled transport modes such as rail and water ones are service dependent.

E. Data Validation by Using Outlier's Detection Method

After collecting context data sets, the next step is data validation. Data validation is set up to avoid a negative event effect. Literature review points to several studies that identify outliers in revised historical data. A lot of research is being done on data validation [2]-[7]. Shen et al. constructed an algorithm designed to quickly elucidate possible outliers and thoroughly investigate their suspicious intentions relative to driving speed [25].

We incorporate the outlier's detection method to revise historical data and apply the Grubbs' outlier test for significance evaluation.

For any historical data sample about the transport corridor's performance, we revise which data have outliers.

There are various outlier test methods, like Grubbs' test (1950), Dixon test (1953), David test (1961), Barnett & Lewis test (1994), Rosner's test (2011). Some of these tests face the problem of misleading situations.

We use the Grubbs data validation method to figure out outliers and make data adjustments. In this article, the method of adjusting outliers is applied with a 99% confidence level. In practice, the Grubbs test has been used to identify defaults in historical transport incidents, and positive results have been reported. The Grubbs test is used to identify outliers that exceed the limits of normal distribution. The result is the probability that indicates the basic data among all the data collected. The complete test method application shows the difference between the sample mean and the extreme data, considering the standard deviation. The test simultaneously determines different probabilities compared to a data set in which normal distribution is assumed.

Based on approximated data, the authors applied the multi-objective optimization method.

F. The Application of Multi-Objective Optimization Method

GAs have been successfully tested on various optimization tasks such as electronic component layout, operations planning, and many others [26]-[34]. GA methods are characterized by simplicity and versatility. The operation of GAs is based on the simulation of the evolution in living nature, i.e. the process of natural selection. The key concepts used to model biological evolutionary processes are "individual" and "population". GAs include a family of metaheuristic methods with the following characteristics: 1) Operations with one or more allowable "populations" of solutions; 2) Individual solutions from one or more "populations" selected for further analysis, processing, giving priority to those solutions that have "better" values of the objective function; 3) Heuristic procedures used to form new permissible solutions by dividing the resulting population into solution pairs and operating with these pairs; 4) Rules used to generate new solutions from individual previously obtained solutions [35].

GAs provide benefits in multi-object optimization when there is a requirement to find all possible trade-offs among multiple criteria [36]. Multi-objective GAs for multi-modal route planning enable a free combination of various transportation modes and provide numerous results based on the trade-off between criteria. Reference [34] proposed GA for urban travel, including public (bus, subway) and private transportation (driving, walking). The variable-length chromosome was used with two levels (intra-modal and inter-modal) crossover and mutation. Multi-objective GA also is used for transportation network optimization [37]. The multi-modal transportation problem is reduced to multi-objective path planning.

We see the multi-modal transportation problem as the planning of multi-objective paths. The transportation network with all transportation modes is represented as a directed graph. A single edge from a node represents an outgoing direct connection from the node to another node in the graph using a single mode of transport (rail, road, water transport).

When destination and origin are known, the graph is simplified. Based on generic expert rules, some nodes can be removed from the graph; for example, nodes that are geographically far away from origin and destination. Also, the focus is on multi-modal terminals, where modes of transportation can be changed. Therefore, some intermediate nodes can be removed, and their sources linked with targets directly. For example, the road network path can be reduced to one edge when it does not involve changing the transportation mode.

In Fig 2, we provide a simple network for transportation from St. Petersburg to Paris to demonstrate our approach. The thick line represents route St. Petersburg – Klaipeda – Kiel – Paris. This route is encoded into a fixed-length chromosome: 121000. All outgoing edges from a node have a number assigned (incrementally from 1). An edge with number 0 represents staying at the same node. This example shows that

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chromosome can be mapped directly to the route. In the example, routes from Kaunas (Kau) to Duisburg (Dui) and Hanover (Han) are represented as separate edges, despite that railway to Duisburg goes via Hanover.

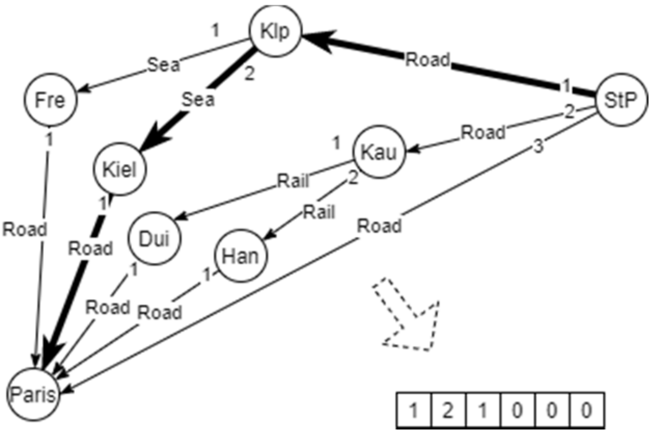

Fig. 2 Schema of selection possibilities of path recognition on the sample transport network

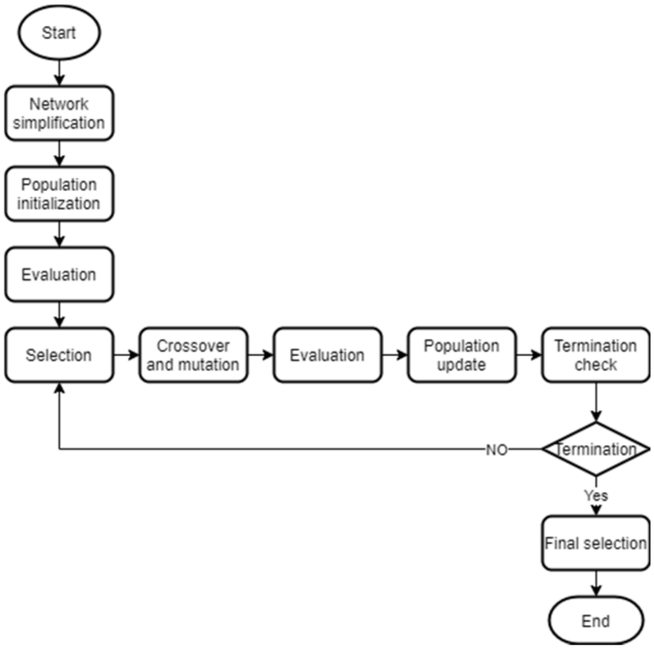

Fig. 3 Adaptation of GA steps for multi-modal transportation

Apart from the additional network simplification step, the process is common to most GAs (Fig. 3). The main steps are:

- Network simplification step is applied for St. Petersburg – Paris example;
- Population initialization is done by calculating solutions using random walk both from the origin (forward) and destination (backwards);
- Evaluation step calculates fitness, which is represented as n_c dimensional vector, where n_c is the number of evaluation criteria;
- Selection step ensures that non-dominated solutions are the highest probability to be selected for the next offspring;
- Crossover and mutation steps allow copying a random set of parent genes, to the same positions in child chromosome. The mutation is changing randomly selected gene to a random number (changing outgoing edge);
- Population update step adds individuals with the highest fitness to the population;
- Termination check limits the duration of the algorithm to the predefined number of cycles;
- User makes the final selection of the best candidate.

This algorithm enables setting non-dominated solutions (Pareto frontier), where a user can choose the best trade-off among objectives.

G. Generated Outputs

The results delivered support decision making in multi-modal transportation processes. Such methodology connects the network of transport corridors with statistics about physical transfer services and dynamic components of the information structures and representation of information flow by all possible and needful channels and the proposition of methods for more optimal decision support. We seek that the output results correspond to the ranking of the transportation corridor. In case some adjustments are required, the GA modification would be possible as the results of multi-objective analysis depend on the weight allocated among data elements in the data set.

The multi-objective analysis covers processing by defining rules on ranking and giving priority to those solutions with "better" values of the objective function.

The methodology can be used in practice, focusing its application on generating better estimates that can be incorporated into the corridor's real-time operation. The application of methodology allows evaluating transport corridors and selecting the one that is the best alternative to use for freight delivery. The proposed set of methods is explicitly included in a richer and wider collection of information linked to the corridor performance. The methodology consists of data validation and solution optimization methods and ranks the transport corridors from the best to the worst in a particular sequence.

The proposed methodology could be used for practical application.

H. Environment for Methodology Application

In real-world, various multi-modal transport corridors could be named. For the application of the methodology, the set of transport corridors are initially defined. Later, the number of transportation corridors is narrowed to the ones that fulfill initial selection objectives. Later on, the multi-objective function is used for the comparison and the ranking of possible alternatives.

A deep representation of knowledge by the semantic model can help choose priorities of the principles and rules provided for specialist experts of different target areas. The adequate imitational models of behavioral analysis allow us to predict further evolution of alternatives and increase the quality of

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decision making. The representation of one of the analyzed corridors is presented in Fig. 4.

The concrete corridor's real environment applied for multi-modal transportation includes all information flows from all participating multi-modal components. Data transfer channels have relations in two directions through them are passing the signals about starting and ending processes in each of participating ways (i.e. A1-A3, W1).

The information of starting and completeness of processes and including the unsuspected and accident events, delays are transmitted fraught these channels accordingly in the West-East or East-West directions (analyzing the Europe region).

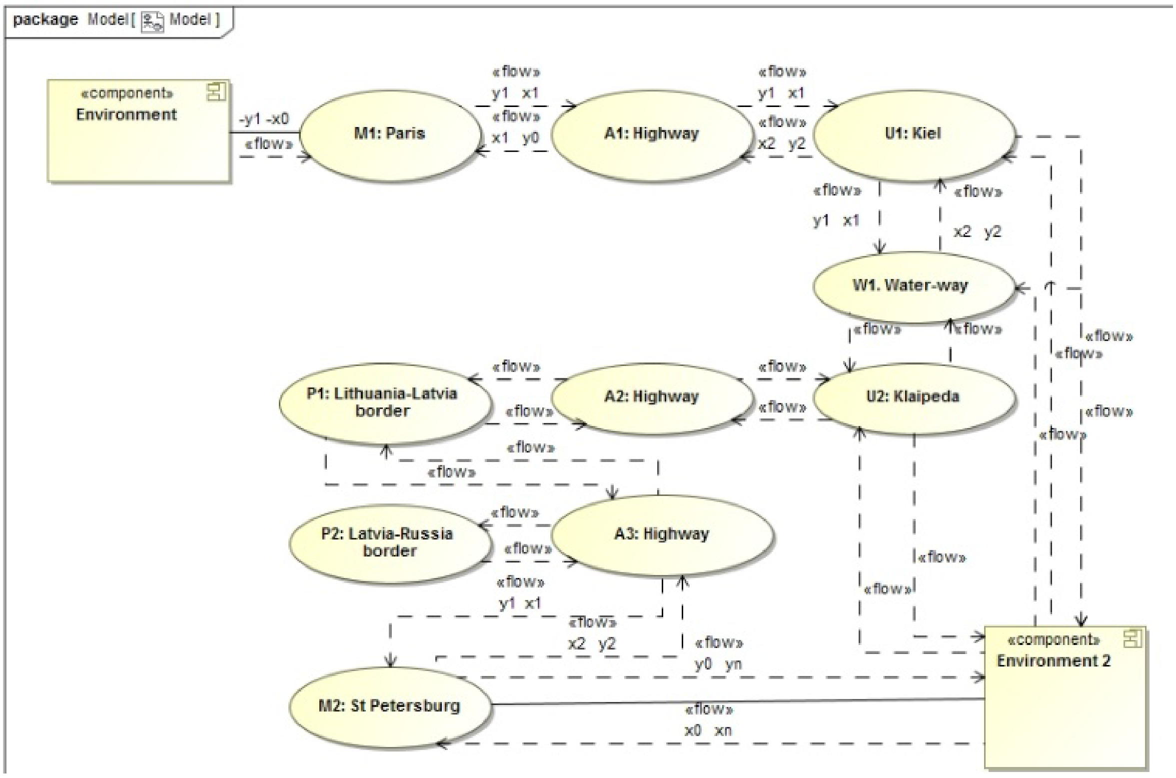

Fig. 4 Example of specification of an alternative corridor in West-East directions of multi-modal transportation of freights in Europe

IV. Conclusions

When formulating and solving transportation process management tasks, many variables are encountered, such as time, price, quantity, location, information flows, security, etc. Therefore, the management of such processes becomes complex and multi-objective. Methods such as linear and nonlinear mathematical models, mathematical-statistical methods, prediction methods (e.g. classical decomposition, trigonometric regression, "Promethee I") are used to implement the process successfully. Information and intelligent transport systems are also used, and various algorithms are applied. The variety of these methods and the synergy of information and intelligent transport systems allow optimal material and information flow management decisions in the transportation process.

The studies which apply GA method in freight delivery are dedicated to find solutions to the VRP. Among these studies, the studies assume that the delivery does not integrate single-mode and multi-modal elements. The number of studies is still small and does not cover the transport corridor selection question, one of the important topics in freight transfer service.

This paper extends the research area and presents methodology applicable for multi-objective analysis in freight delivery process. The methodology follows the compositing elements: physical-technical characteristics of multi-modal transportation networks, and context data sets about safety and freight delivery duration in alternative transport corridors. The methodology includes the methods for data validation, i.e. Grubb's outliers' detection and solution optimization method using GA what ranks the transport corridors from the best to the worst in a particular sequence. The methodology must be tested for practical application by using historical estimates or real-time data validated estimates.

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D. Dzemydienė is leading professor, the chief research fellow working at the Department of Business Technologies and Entrepreneurship of the Faculty of Business Management of Vilnius Gediminas Technical University (Lithuania) and at the Institute of Data Science and Digital Technologies at the Faculty of Mathematics and Informatics of Vilnius University (Lithuania). She holds a diploma of habilitation doctor procedure in 2004 and professor diploma in 2009. She published more than three hundred research articles, three manual books, and three monograph books with co-authors. She is head of the Legal Informatics Section of Lithuanian Computer Society (LIKS), a member of the European Coordinating Committee for Artificial Intelligence (ECCAI), and Board member of the Lithuanian Operation Research Association. Her research interests include artificial intelligence methods, decision support systems, evaluation of sustainable development processes, and smart services.

A. Burinskienė is associated professor in Vilnius Gediminas Technical University, Lithuania. She defended PhD thesis ten years ago in Social science, economics in Vilnius, Lithuania. Her interests' area is ICT, logistics and supply chain. She has published more 70 publications.

A. Miliauskas is specialist engineer working at the Department of Business Technology and Entrepreneurship in Vilnius Gediminas Technical University, and at the Institute of Data Science and Digital Technologies at the Faculty of Mathematics and Informatics of Vilnius University (Lithuania). He defended the Master degree of Informatics at Vilnius University. He published about 15 scientific articles. His research interest includes artificial intelligence methods and smart service development platforms.

K. Čižiūnienė is associated professor in Vilnius Gediminas Technical University, Lithuania. She defended PhD thesis ten years ago in Social science, economics in Vilnius, Lithuania. Her interests' area is transport, logistics. She has published more than 60 publications.