MODELING DEMAND FOR TRANSPORT SERVICES AS FLOW OF REQUESTS

[1]Vitalii NAUMOV, [1]Hanna VASIUTINA

[1]Cracow University of Technology, Kraków, Poland, EU,
vitalii.naumov@pk.edu.pl, hanna.vasiutina@doktorant.pk.edu.pl

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Abstract

The paper presents an approach and corresponding software to model demand for transport services on the grounds of the requests flow model. The authors propose the models of demand simulation for different types of transport systems – a freight forwarding company, a public transport network, and a parking lot. In this paper, we propose basic classes implemented in the Python programming language that allows researchers to simulate the demand for transport services in the mentioned systems: the demand simulation procedures are described in detail, and references on the examples of their use are given.

Keywords: Transport demand, requests flow, computer simulations, Python programming

1. INTRODUCTION

The demand model is an essential element in any decision support model in the field of transport and logistics. The adequacy of the applied demand model and the data used to develop it assure correct simulation results of a system functioning. Modeling of demand for transport services is a particularly complex problem due to a large number of stochastic factors forming demand and limited access to sources of up-to-date demand parameters.

The development of information technologies over the past years has provided a high level of informatization and virtualization of technological processes in contemporary transport markets. This has granted transport planners the possibility to develop more precise demand models based on big amounts of data obtained in the real-time mode [1].

The literature analysis [2-5] suggests that the task of estimating demand for transport services is usually considered a numerical evaluation of a single parameter used to characterize customers' needs. In most of the existing approaches, the estimation of demand parameters is based on the determination of their predicted values. Typically, the predicted value of a parameter is determined on the base of statistical data for previous periods, which makes it much more difficult to study the processes of demand-shaping. Such an approach yields incorrect estimates of the demand parameters. The classical four-step approach [6] could be effectively used in transport planning macro-models, but it cannot be considered as a proper tool for demand simulations at the level of a single public transport line, or for modeling demand for such transport systems as parking lots or logistics centers.

We propose to describe the demand for cargo deliveries based on a model of the requests' flow, which generates corresponding informational, material, and financial flows in a transport system. Such an abstraction corresponds to the used principles of communication between the transportation market entities. For example, in the modern markets of the road freight transportation, ensuring the needs of freight owners for cargo deliveries and the needs of carriers for vehicles' load in most cases is provided under the mediation of a freight forwarding company as an operator servicing the flow of information about clients' requests; as the other example, the parking lot could be considered: needs of drivers to park their vehicles at the certain parking form the requests flow which represents demand for services; also the needs of passengers for trips could be represented as a flow of requests at the given stops of a public transport system, etc.

This paper aims to represent an approach to modeling transport demand as a flow of requests characterized by a set of numeric parameters. In the second section, we depict the methodology of demand simulations with a brief description of base classes used in models; the third part contains examples of how to use the described concept for different transport systems: cases of a parking lot, a forwarding company and a public transport network are considered; the last section ends the paper with brief conclusions.

2. METHODOLOGY

The basic unit in the demand model is a request for transportation services – a need of a client for services, supported by its purchasing abilities and presented at the market to be satisfied. A set of potential and actual requests for the transport company's services forms the demand for its services. Since a set of consecutive requests for services of transport companies characterizes demand, the demand estimation problem could be transformed into the problem of the request flow parameters estimation.

A model $\mathbf{D}$ of demand for transport services could be presented as an ordered set of requests:

$$\mathbf{D} = \{\boldsymbol{\rho}_i\},\ i = 1 \ldots \eta \tag{1}$$

where:

$\boldsymbol{\rho}_i$ is the *i*-th request in a flow

η is the number of requests in a flow

Each request for transport services could be characterized by numerous parameters. In the demand model, the most significant characteristics influencing the technological process of transportation should be considered:

$$\boldsymbol{\rho}_i = \{t_i,\ p_{1i},\ p_{2i}, \ldots, p_{ni}\} \tag{2}$$

where:

t_i is a time moment of the *i*-th request appearance

p_{1i}, p_{2i}, …, p_{ni} are numeric parameters of the request (e.g., a shipment weight, delivery or travel distance, parking duration, etc.)

Note that the set $\mathbf{D}$ is ordered according to values of the appearance time:

$$t_1 \le t_2 \le \ldots \le t_{\eta-1} \le t_\eta \tag{3}$$

The request numerical parameters are deterministic for single requests, but a sample of the parameter for all the requests in the $\mathbf{D}$ set characterizes respective random variables. Thus, demand for cargo deliveries could be described on the basis of a tuple $\langle \zeta, \vartheta_1, \vartheta_2, \ldots, \vartheta_n \rangle$, where ζ is a random variable of a time interval between requests in a flow, ϑ_1, ϑ_2, …, ϑ_n are random variables characterizing other numeric demand parameters. Thus, a time moment of the *i*-th request appearance is be defined on the grounds of realization $\tilde{\zeta}$ of the variable ζ:

$$t_i = \begin{cases} \tilde{\zeta},\ i = 1, \\ t_{i-1} + \tilde{\zeta},\ i > 1. \end{cases} \tag{4}$$

The geographic location of origin and destination points (e.g., consignors and consignees location, the bus stops location) we propose to describe on the basis of a two-dimensional set, in which the rows characterize the region, where the origin points can possibly be located, and the columns – the corresponding regions for destination points. The elements of such a set are sets of requests $\mathbf{r}_{ij}$, for which an origin is located in the *i*-th region, and a destination – in the *j*-th region. For a flow with a finite number of elements, the set can be replaced by a numeric characteristic – the origin-destination matrix $\boldsymbol{\Delta}$, in which elements δ_{ij} reflect the ratio of the number of requests in $\mathbf{r}_{ij}$ and the number η of requests in the flow:

$$\delta_{ij} = \frac{\eta\left(\mathbf{r}_{ij}\right)}{\eta} \tag{5}$$

where:

$\eta\left(\mathbf{r}_{ij}\right)$ is the number of elements in the set $\mathbf{r}_{ij}$

To obtain data samples and to model demand for transport services, we developed the appropriate simulation procedures using the Python programming language. The conceptual structure of basic classes, used for demand simulations, is presented in **Figure 1**.

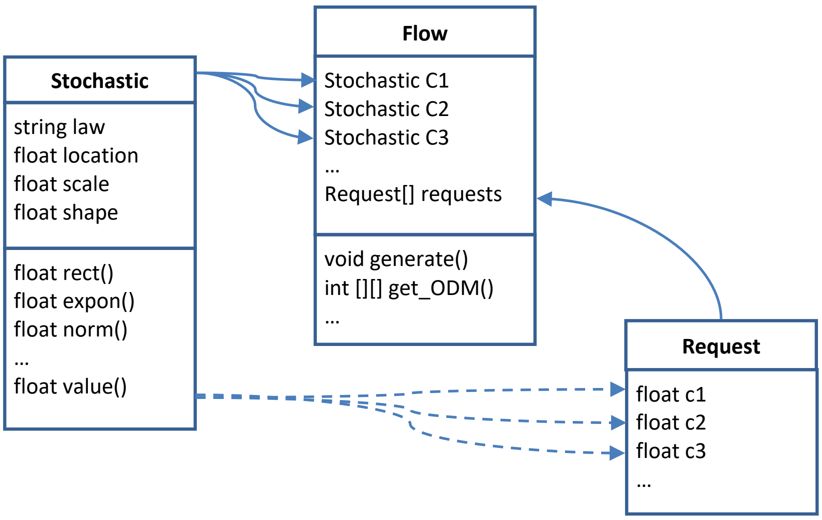

Figure 1 Basic classes for modeling demand as the requests flow

The *Stochastic* class is a basic class to model requests flow parameters as stochastic variables: it contains fields representing the distribution law and its numeric characteristics – parameters of location, scale, and shape. Values of random variables are generated by the given distribution by the corresponding methods (representing rectangular, exponential, normal, and other distributions) and are returned with the *value* method.

The *Flow* class represents a model of demand for transport services: its field of the *Stochastic* type describe numeric parameters of requests, which are stored in the *requests* list. To operate with the demand model, the necessary functions are provided, such as *generate* generating the requests flow, or *get_ODM* returning the origin-destination matrix. A certain request is described as an instance of the *Request* class containing fields with the generated numeric parameters.

Certain implementations of the classes in the presented demand model could contain additional fields and methods used to describe the transport system being simulated or to solve the given problem.

3. CASE STUDIES

3.1. Parking Lot

Demand for parking services could be characterized by the number of vehicles, parked at the lot during the given time, and by the parking duration of a vehicle. For the given period, instead of the parked vehicle's number, we propose to use a random time interval between arrivals of vehicles. Thus, the parking demand $\mathbf{D}_{PL}$ could be described by a pair of stochastic values – the parking interval and the parking duration:

$$\mathbf{D}_{PL} = \left\{\tilde{\zeta}_{PL}, \tilde{t}_{PL}\right\} \quad (6)$$

where:

$\tilde{\zeta}_{PL}$ is the random variable of the time interval between arrivals of two vehicles

$\tilde{t}_{PL}$ is the random variable of parking duration per a vehicle

The presented model of demand for the parking lot services is used in [7] for estimations of parking lot capacity. The code of a parking lot model is available at https://github.com/naumovvs/parking-lot-model.

3.2. Freight Forwarding Company

A set of current and potential requests for forwarding services shapes the demand for a forwarding company's services; correspondingly, a set of requests for services of all forwarding companies in the region represents the demand for freight transport services in the region, etc. A single request ρ in this case can be described based on the following numeric parameters:

$$\rho = \left\{\zeta, \omega, \tau, \theta\right\} \quad (7)$$

where:

ω is the shipment volume

τ is the time between the moment when the shipment is to be delivered and the moment when the order was placed in the system (acceptable waiting time)

θ is a type of vehicle needed to service the request (box, van, dump, container, etc.)

For a single request, the presented parameters are deterministic characteristics, however, for the requests flow, numeric parameters (ζ, ω and τ) should be considered as random variables, and possible values of the variable θ could be characterized by the respective probabilities. Thus, the final model $\mathbf{D}_{FFC}$ of demand for freight forwarding services could be presented as a set of the listed above characteristics of the requests' flow:

$$\mathbf{D}_{FFC} = \left\{\mathbf{\Delta}, \tilde{\zeta}, \tilde{\omega}, \tilde{\tau}, \mathbf{p}_{\theta}\right\} \quad (8)$$

where:

$\tilde{x}$ is the stochastic variable characterizing the demand numeric parameter x

$\mathbf{p}_{\theta}$ is a vector, the *i*-th element of which is the probability that the *i*-th type of a vehicle body will be needed to serve a request

Information on the requests' flow for a given forwarding company can be obtained from the data about the requests serviced by the forwarder. As it's mentioned in [8], data on the requests' flow for the given segment of the freight transportation market can be obtained at the specialized logistics portals.

The described demand model was used in the optimization problem of estimating the number of vehicles [9]. The Java implementation of this demand model can be downloaded from https://www.academia.edu/31832379; also, a simple version of the simulation model solving the optimal vehicles number problem implemented in Python is available at https://www.academia.edu/32280513.

3.3. Public Transport Net

Public transport demand $\mathbf{D}_{TN}$ we propose to present as a set of passengers intending to use the public transport. Each element of this set could be described on the basis of the following parameters:

$$\pi_i = \{\eta_i, \mu_i, \mathbf{P}_i, \tau_i\}, \pi_i \in \mathbf{D}_{TN} \tag{9}$$

where:

π_i is the *i*-th passenger; η_i and μ_i are origin and destination stops of a trip for the *i*-th passenger

$\mathbf{P}_i$ is a set of transfer stops where the *i*-th passenger changes lines within his trip

τ_i is a moment of time when the *i*-th passenger appears at the bus stop η_i in order to perform a trip

In order to simulate demand for travel, it is quite convenient to divide all the elements of the set $\mathbf{D}_{TN}$ into groups according to the stops of the public transport network where the trips begin:

$$\mathbf{D}_{TN} = \bigcup_{j=1}^{N_L} \mathbf{D}_{TN\,j} \tag{10}$$

where:

N_L is the number of stops in the public transport net

$\mathbf{D}_{TN\,j}$ is a group of passengers travelling from the *j*-th stop of the bus line:

$$\mathbf{D}_{TN\,j} = \{\pi_i : \eta_i = j\} \tag{11}$$

Thus, for each group $\mathbf{D}_{TN\,j}$, the parameters τ_i for the set elements can be defined on the grounds of realization of the random variable ζ_j:

$$\tau_i = \begin{cases} \tilde{\zeta}_j, \ i = 1, \ \eta_i = j, \\ \tau_{i-1} + \tilde{\zeta}_j, \ i > 1, \ \eta_i = j, \end{cases} \tag{12}$$

where:

$\tilde{\zeta}_j$ is the realization of the random variable of an interval between passengers' appearances at the *j*-th stop

The demand model, described above, is used for solving the problem of modeling the demand for transfers of passengers in a city public transport system [10]. The implementation of the model in the Python programming language can be forked from the repository https://github.com/naumovvs/publictransportnet.

4. CONCLUSION

The proposed approach allows researchers and transport managers to consider the stochastic nature of demand for transport services. The developed software for modeling of demand for transport services is a tool for estimations of numerical parameters of the requests flow as random variables, which also considers the distribution of demand concerning geographic regions (if it is relevant). The proposed class library for modeling interactions between transport market entities is an effective tool for modeling demand for transport services, as evidenced by the results of the simulation experiments.

The demand model based on the presented approach could be used as a subsystem of other more sophisticated simulation models to solve several problems in the area of transportation systems management, for example: defining the strategies of companies in the transport market, developing effective variants of the customer service processes, improving the vehicles fleet structure, etc.

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