OPTIMISATION OF THE NUMBER OF OWN VEHICLES FOR WAREHOUSE SUPPLY AND DELIVERY IN CASE OF ONE WAREHOUSE, SHUTTLE SERVICES AND STOCHASTIC CAPACITY NEEDS

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Abstract: The general goal of research is the optimisation of the number of own vehicles performing supply and delivery in case of a logistic service centre that has warehouses, if needs stochastically change. The purpose of this paper is to present the structure of the problem investigated from which the different variants can be derived and to present a simpler model, when the warehouse system consists of only one warehouse and supply and delivery are carried out by shuttle services. Main goal of optimisation is to determine the number of own vehicles by minimizing the total cost function. For the determination of the number of own vehicles it is essential to schedule vehicles, to select the adequate simple and expanded shuttle services.

Keywords: model, warehouse supply and delivery, stochastic needs, shuttle service, costs.

1. Introduction

Performing different logistic services with the help of a company's own resources is not commercially viable for every firm that is why recently logistic service companies have come to the front. These logistic service companies specialized for one or more logistic activities and they can provide logistic services satisfying high quality requirements. Main goal of these service companies is to carry out their activities with minimizing costs and increasing the quality of service.
The general goal of research is the optimisation of the number of own vehicles performing supply and delivery in case of a logistic service centre that has warehouses, if needs stochastically change, and there can be different variants of the warehouse system and the connected supply and delivery. The aim of this paper is to present the structure described above from which the different variants can be derived, and of which the solution methods and results are different compared to each other. Furthermore, to present a simpler model, when the warehouse system consists of only one warehouse and supply and delivery are carried out by shuttle services.

2. Description of the elements and characteristics of structure

The structure of different variants of warehousing, supply and delivery:

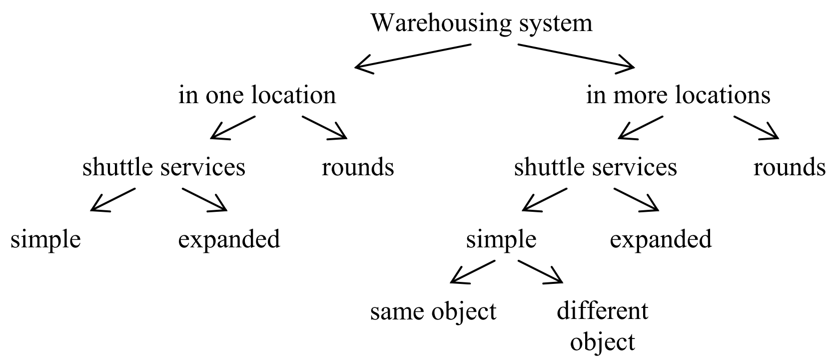


Figure 1 The structure of the system investigated

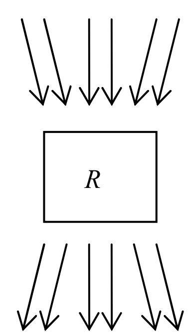


Figure 2 One warehouse

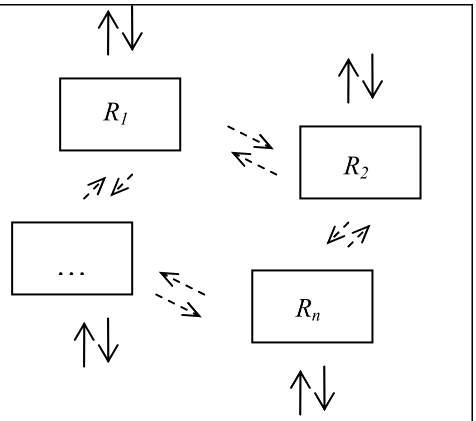


Figure 3 More warehouses

It can be seen from the structure above that two main cases are distinguished, in the first, the warehouse system consists of one warehouse, in the second two or more warehouses belong to the system.

Possible connections among warehouses, suppliers and customers are provided by the matrix of connections (K). In case of one warehouse this matrix contains obviously only the suppliers and customers that are in transportation connected with the given warehouse. Besides, the path matrix (L) is also important, which gives the distance by road between the different objects.

Matrix of connections

$$K = \begin{array}{c} \\ R_1 \\ \vdots \\ R_m \\ B_1 \\ \vdots \\ B_n \end{array} \begin{array}{c} R_1 \; \dots \; R_m \; V_1 \; \dots \; V_g \\ \left[\begin{array}{ccc} & & \\ L_{11} & & L_{12} \\ & k_{ij} & \\ L_{21} & & L_{22} \\ & & \\ & & \end{array} \right] \end{array}$$

where

$k_{ij} = 0$ or 1, in the relation where there is delivery $k_{ij} = 1$ otherwise $k_{ij} = 0$

$R_1, \ldots R_m$ denote the warehouses,

$B_1, \ldots B_n$ denote the suppliers,

$V_1, \ldots V_g$ denote the customers.

Path matrix

$$L = \begin{array}{c} \\ R_1 \\ \vdots \\ R_m \\ B_1 \\ \vdots \\ B_n \end{array} \begin{array}{c} R_1 \ \ldots \ R_m \ \ V_1 \ \ldots \ V_g \\ \left[\begin{array}{ccc} & & \\ L_{11} & & L_{12} \\ & l_{ij} & \\ L_{21} & & L_{22} \\ & & \\ & & \end{array} \right] \end{array}$$

where

l_{ij} : the shortest road length between object *i* and object *j*.

Models of transport arrangement investigated are the same as models applied in practice, these are the shuttle services (simple, expanded shuttle services) and rounds. In case of a simple shuttle service a vehicle transports goods from the sender object to the receiver object and goes back empty until it carries out the whole task or the working time is over. Expanded shuttle services differ from this in the fact that beside one sender and one receiver object, the service contains at least one more object (sender or receiver object). Rounds can be applied when transportation tasks of small quantities and more stations have to be carried out. This means that the truck is loaded at one station and at consecutive stations it is progressively unloaded, or it is progressively loaded and unloaded at one station.[7]

As it was mentioned the aim is the optimisation of the number of own vehicles when needs stochastically change. Considering the system in which there are more warehouses, the operation of the system is much more difficult because transportation is possible among warehouses too. It is an essential question for example, among others obviously, that how much is the quantity which has to be unloaded at the first warehouse, how much has to be delivered to another one, when a transfer is reasonable and what kind of service has to be used for the transfers among warehouses.

Intensity of material flow among objects can be characterised by the matrix of material flow. The element q_{ij} denotes the intensity of material flow between object *i* and object *j* for time unit. Material flow can be deterministic, that is it has been already defined, determined or it can be determined, computed; or stochastic, that is it can be influenced by random effects, thus it can only be described by random variables.

$$Q = \begin{array}{c} \\ R_1 \\ \vdots \\ R_m \\ B_1 \\ \vdots \\ B_n \end{array} \begin{array}{c} R_1 \ \ldots \ R_m \ \ V_1 \ \ldots \ V_g \\ \left[\begin{array}{c} \\ \\ q_{ij} \\ \\ \\ \\ \end{array} \right] \end{array}$$

$$q_{ij} = \left[\frac{LU}{day}, \frac{LU}{week}, \frac{LU}{month} \right]$$

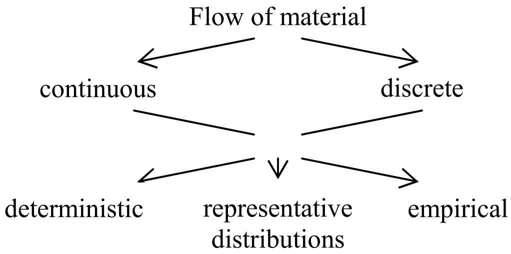


Figure 4 Characteristics material flow

Another important question is what kind of vehicles has to carry out the warehouse supply and delivery. As it can be seen from the following figure, we investigate two cases, in the first the vehicle fleet available is homogeneous, it consists of vehicles of the same type and capacity, in the second it is inhomogeneous, that is it consists of vehicles of different types. If the vehicle fleet is homogeneous we can consider a model variant in which vehicles are of a given type, one in which the type is part of the optimisation task and when the fleet is inhomogeneous an optimisation task can be also the determination of the optimal combination of vehicles.

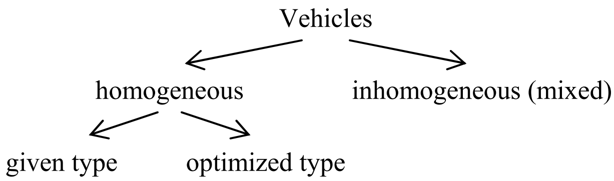


Figure 5 Possible cases of vehicle fleet

When the structure is investigated it has to be fixed what kinds of costs are considered. In case of own vehicles the cost components are the cost of maintenance which is constant for time unit and it is independent of usage, and the cost of operation which can be divided into four parts, the cost of no-load running, the load proportional cost, cost of loading and waiting. Cost of no-load running depends on the path length, the load proportional cost depends on the load and path length, the cost of loading depends on the number of loading units and cost of waiting which is in proportion to the waiting time to loading and unloading channels. Cost of rent depends on the type of vehicle, the number of vehicles rented a day, its standard deviation, the average load and its standard deviation, the ordering date of demand, but in case of more warehouses it does not depend on the fact to which warehouse they are assigned.
Summarising, in case of the structure above the task is to determine:

- homogeneous or mixed vehicle fleet, in case of inhomogeneous optimal combination,
- the number of own vehicles,
- vehicle type
  - non-convertible (in case of one warehouse),

- convertible (in case of more warehouses, if a vehicle is underemployed at a warehouse, then it can be re-routed after it carries out its whole task).

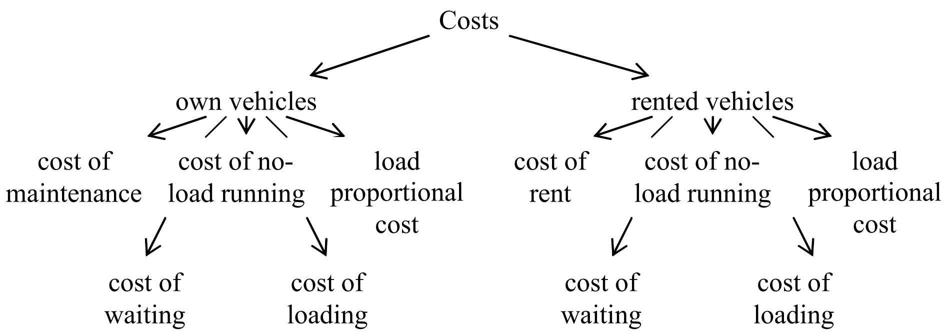


Figure 6 Structure of costs connected to transportation

3. Description, data and objective function of the model in case of one warehouse and shuttle services

In the first model analysed the warehouse system consists of one warehouse and the aim is to optimize the number of vehicles carrying out supply and delivery, when needs stochastically change and the supply and delivery are made by simple and expanded shuttle services.
In case of the system of one warehouse the matrix of connections described in the general structure is reduced to one line or column. The path matrix is modified as it can be seen in the following:

$$L' = \begin{matrix} R \\ O_1 \\ \vdots \\ O_n \end{matrix} \overset{\begin{matrix} R & O_1 & \dots & O_n \end{matrix}}{\begin{bmatrix} & & & \\ & & l_{ij} & \\ & & & \end{bmatrix}}$$

$L' = L_{22}$ if $n = g$, plus one row and column. In case of object O_i and O_j we do not make difference between a supplier and customer, because one object can be supplier and customer also.
Matrix L' in general is a symmetric matrix, that is $l_{ij} = l_{ji}$, and it is needed in case of expanded shuttle services and rounds (distance between different objects), but when simple shuttle services are considered the path matrix becomes a single-row or a single-column matrix.
The model is reduced by the following general conditions:

- given capacity of vehicles,
- homogeneous vehicles,
- constant loading time is connected to the time of delivery in the warehouse, at the supplier and customer,
- the number of suppliers and customers are constant.

Deterministic input data of the reduced model:

- matrix of connections,
- path matrix,
- specific costs,
- capacity of vehicles (in case of homogeneous vehicles and homogeneous loading units),
- average speed of vehicles,
- average time of loading and unloading for loading units,
- average waiting time.

When we investigate the input data of the reduced model two sub-models, model *A* and *B*, can be distinguished by whether the number of loading units is known for every relation or only its total value is known.

Model A

Model *A* concerns that case when the whole model is reduced to one warehouse. Model *A* does not make difference among lines of goods by relations. When determining the number of vehicles in a simplified case the turnover of goods is measured only in loading units that is, it does not distinguish loading units by lines of goods. For the determination of the number of vehicles it is not essential to know the number of loading units by relations coming in and going out a day. A further condition is the date on a day of the supply and delivery to and from the warehouse can be arbitrary. Moreover, it has to be considered that it can not be regarded constant but random effects have to be taken into account. For that reason the flow of material coming in and going out a day can be described by distribution functions:

- the number of loading units arriving from supplier *i* to the warehouse: $F_i^B = F_i^B(q_i^B)$,
- the number of loading units going out from the warehouse to customer *j*: $F_j^K = F_j^K(q_j^K)$,

where $q_i^B = \left[\frac{LU}{day}\right]$ and $q_j^K = \left[\frac{LU}{day}\right]$ denote the flow of material coming in and going out a day.

Model B

Model *B* concerns also the one warehouse case. However, this model makes difference among lines of goods by relations. Here loading units, as the flow of material coming in and going out by line of goods a day can be described by the following distribution functions:

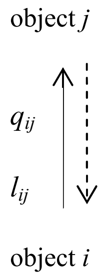
- the number of loading units arriving from supplier *i* to the warehouse from the line of good *p*: $F_{ip}^B = F_{ip}^B(q_{ip}^B)$,
- the number of loading units going out from the warehouse to customer *j* from the line of good *r*: $F_{jr}^K = F_{jr}^K(q_{jr}^K)$,

where $q_{ip}^B = \left[\frac{LU}{day}\right]$ and $q_{jr}^K = \left[\frac{LU}{day}\right]$ denote the flow of material coming in and going out a day from goods *p* and *r*.

As we mentioned in the case investigated now supply and delivery are performed by simple or expanded shuttle services. Shuttle services can be characterized by average route length (time of transportation), its standard deviation, the proportion of unloaded running to loaded ones and average route increment (in case of expanded shuttle services).
For the optimal operation of the system it is essential to evaluate the different variants of transport. In the model loading utilization is to be analysed.

a) simple shuttle service

$$\varphi_{\ddot{u}} = \frac{q_{ij} + q_{ji}}{2C_{0\nu}}$$

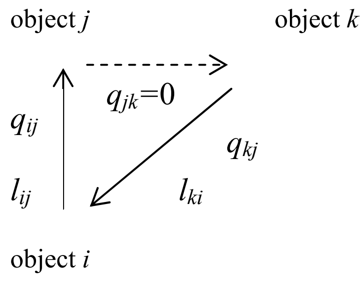


$$q_{ij} \neq q_{ji}$$

and $C_{0\nu}$ denotes the capacity of the vehicle

b) expanded shuttle service (it is possible when object *j* and *k* have an appropriate task)

$$\varphi_{\ddot{u}} = \frac{\frac{l_{ij}}{L_{ik}} q_{ij} + \frac{l_{ki}}{L_{ik}} (q_{ki} + q_{jk}) + \frac{l_{jk}}{L_{ik}} q_{jk}}{C_{0\nu}}$$



$$L_{ik} = l_{ij} + l_{jk} + l_{ki}$$

route increment: $\alpha = \dfrac{l_{ij} + l_{jk} + l_{ki}}{2l_{ij}}$

It has to be evaluated in case of the different variants of shuttle services:

- how they increase the costs of own vehicles,

- how they decrease the efficiency,
- how they decrease the loading utilization of vehicles,
- how they decrease the number of rented vehicles.

The optimal solution of a task can be developed by an objective function or functions. Our objective function consists of cost components appeared in the general description of the structure are used for the expression of total cost ($K = \left[\frac{Euro}{day}\right]$), that is the maintenance cost of own vehicles, costs of no-load runs and the load proportional cost, cost of loading and waiting. In case of rented vehicles the cost of rent, and as for own vehicles, costs of no-load runs, load proportional cost, cost of loading and waiting.

$$K = K_F^S + K_{SÜ}^S + K_{ST}^S + K_R^S + K_W^S + K_B^B + K_{SÜ}^B + K_{ST}^B + K_R^B + K_w^B$$

4. Optimisation task for the number of own vehicles

Main goal of optimisation is to determine the number of own vehicles by minimizing the total cost function. For the determination of the number of own vehicles it is essential to schedule vehicles of supply and delivery, to select the adequate simple and expanded shuttle services. In the optimisation the costs of different variants are evaluated in case of simple shuttle services and in case of expanded shuttle services, and the variant that is more favourable, has less cost becomes the optimal one.

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