A RANDOM SEARCH ALGORITHM FOR CYCLIC DELIVERY SYNCHRONIZATION PROBLEM

ABSTRACT

Background: The paper is devoted to the cyclic delivery synchronization problem with vehicles serving fixed routes. Each vehicle is assigned to a fixed route: the series of supplier's and logistic centers to be visited one after another. For each route the service frequency is fixed and known in advance. A vehicle loads at a supplier's, then it delivers goods to a logistic center and either loads other goods there and delivers them to the next logistic center along the route or goes to another logistic center. Each logistic center can belong to several routes, so goods are delivered there with one vehicle and then they departure for the further journey with another truck. The objective of this cyclic delivery synchronization problem is to maximize the total number of synchronizations of vehicles arrivals in logistic centers and their load times, so that it is possible to organize their arrivals in repeatable blocks.

Methods: Basing on the previously developed mathematical model for this problem we built a random search algorithm for cyclic delivery synchronization problem. The random heuristic search utilizes objective-oriented randomizing. In the paper the newly-developed random search algorithm for cyclic delivery synchronization problem is presented.

Results: A computational experiment consisted of employing the newly-developed random search algorithm for solving a series of cyclic delivery synchronization problems. Results obtained with the algorithm were compared with solutions computed with the exact method.

Conclusions: The newly-developed random search algorithm for cyclic delivery synchronization problem gives results which are considerably close to the ones obtained with mixed-integer programming. The main advantage of the algorithm is reduction of computing time; it is relevant for utilization of this method in practice, especially for large-sized problems.

Keywords: cyclic delivery synchronization n problem, mixed-integer programming, optimization, heuristic algorithms, random search

INTRODUCTION

Internal logistics management system controls processes of handling, loading and discharging goods as well as document circulation. Logistic centers are interested in making warehousing and inventory management as efficient as possible, so that utilization rate of storage areas can increase, inventory costs can decrease, and level of customer service quality can significantly raise. The ways to obtain these goals are: shortening time of receipting and dispatching operations, speeding-up handling operations, eliminating or reducing bottlenecks in handling and warehousing processes [Gudehus and Kotzab 2009].

In a system of cyclic deliveries where deliveries are performed repeatedly along fixed routes with fixed frequencies synchronization of vehicles at logistic centers becomes even more important. Such deliveries are common in food industry, where perishable goods are delivered to customers along fixed routes on regular basis [Akkerman et al. 2010]. It is also to be observed is manufacturing and services where one supplier provides numerous customers with some products or services and the customers' demand is not high and it changes on the seasonal basis [Ching-Ter and Hsiao-Ching 2013, Ekici et al. 2014, Lee and Fu 2014]. Scheduling periodic services – e.g. waste collecting – is also an important problem in municipal services management [Kazan et al. 2012].

Synchronization of cyclic deliveries is crucial for supply chain management, where cargo needs to be trans-shipped and the problem becomes even more complicated when there are time windows for arrivals [Ulrich 2013] or some deliveries' departure times or arrival times are established in advance and cannot be changed [Leunga and Chen 2013, Zheng et al. 2015] or there is a need to minimize the number of vehicles serving the system [Campbell and Hardin 2005] or to minimize the total costs [Rad et al. 2014, Laporte et al. 2017]. When some cargo needs to be trans-shipped or handled in a logistic center before the next part of its journey, it becomes crucial to synchronize arrivals of vehicles used for consecutive parts of the cargo's journey. Synchronization can result in reducing the amount of time needed for handling operations as well as in reducing the cargo's waiting time, so cargo can be temporarily stored in the storing area next to the loading ramp. The efficiency of the given loading ramp increases, because the loading ramp handling devices are calibrated once and they can be utilized both for unloading one vehicle and loading another [Groenevelt et al.1992, Kazan et al. 2012, Gdowska and Książek 2013, Gdowska and Książek 2015].

This paper is devoted to the cyclic delivery synchronization problem in a network of manufacturers' plants and logistic centers with vehicles serving fixed routes. The objective of the formulation of cyclic delivery synchronization problem, to which this paper refers, is to obtain such synchronization of vehicles arrivals in logistic centers and load time, so that it is possible to organize their arrivals in repeatable modules. The authors consider synchronization as a situation when the amount of time between arrivals of two vehicles serving different routes is in a predefined range. A mixed-integer programming (MIP) model was developed for the cyclic delivery synchronization problem with vehicles serving fixed routes [Gdowska and Książek 2015]. Cyclic delivery scheduling problem belongs to NP-hard problems [Groenevelt et al.1992, Raa and Dullaert 2007], so it is not possible to obtain optimal solution for medium-sized and large-sized problems. Therefore, there was a need to develop a heuristic algorithm for the cyclic delivery scheduling problem, so that we can obtain feasible solutions despite the size of the problem. In this paper a newly-developed random search algorithm for the cyclic delivery scheduling problem is presented. The algorithm was employed for solving a selection of problems – in the paper computational experiments are presented and obtained results are reported.

CYCLIC DELIVERY SYNCHRONIZATION PROBLEM – A BRIEF DESCRIPTION AND A MIXED INTEGER PROGRAMMING MODEL

Detailed description of the cyclic delivery synchronization problem was presented in the previous works of the authors [Gdowska and Książek 2013, Gdowska and Książek 2015]. Here we provide essential assumptions adopted in this approach to the cyclic delivery synchronization problem. Each vehicle is assigned to one route to which suppliers and logistic centers belong; logistic center can be a trans-shipment node for one route as well as a final customer for another. A vehicle is loaded at a supplier’s, then delivers cargo to a series of logistic centers and finally goes back to the supplier’s. Routes are fixed and known in advance as well as delivery size. For every route the interval between departures of consecutive vehicles from the supplier’s is fixed and known. the scheme of the problem is presented in the Figure 1.

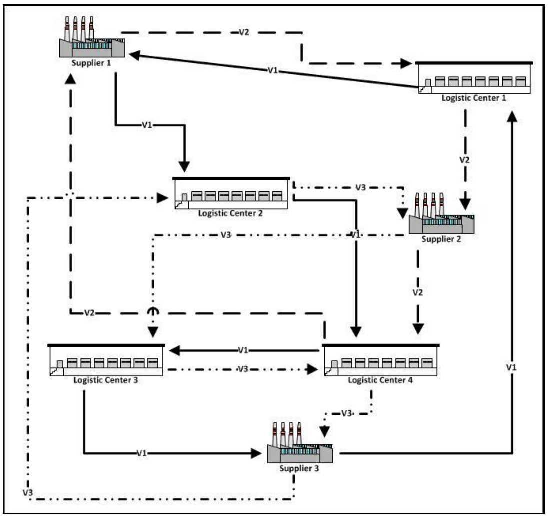


Fig. 1. Scheme of a network where synchronization of cyclic deliveries to logistic centers is needed. Source: [Gdowska and Książek 2015].

Rys.1. Schemat sieci w której występuje potrzeba harmonogramowania dostaw cyklicznych do centrów przeładunkowych. Źródło: [Gdowska i Książek 2015].

In the MIP model the objective is to maximize the number of synchronizations in the system. Synchronization of two vehicles serving different routes is achieved in node *b* when the interval between arrivals of these vehicles in node *b* are in the range (w_b; W_b). Two types of decision variables were utilized: continuous non-negative variable X_{ip} – the departure time of the *p*-th delivery of *i*-th route, and binary variable Y_{ijbpq} – it stands for the existence or nonexistence of synchronization between every pair of arrivals of vehicles serving different routes at the node *b*. Notation used in the MIP model for the cyclic delivery synchronization problem is presented in Table 1 and the model is presented in Table 2.

Due to the fixed routes and desirable synchronization of arrivals at nodes shared by different routes this approach to the cyclic delivery synchronization problem is similar to the one of approaches to the bus timetabling synchronization problem [Ceder et al. 2001, Eranki 2004, Ibarra-Rojas and Rios-Solis 2012,] the MIP model for cyclic delivery synchronization problem [Gdowska and Książek 2015] was based on the BTP model [Ibarra-Rojas i Rios-Solis 2012].

Table 1. Notation used in MIP model for the cyclic delivery synchronization problem

Tabela 1. Oznaczenia zastosowane w modelu programowania całkowitoliczbowego mieszanego dla problemu synchronizowania cyklicznych dostaw

Sets:	
I	– set of routes
B	– set of nodes (logistic centers)
J^{ij}	– set of pairs <*i*, *j*>, where *i*-th and *j*-th routes share a node
S^{ijb}	– set of triples <*i*, *j*, *b*> where *i*-th and *j*-th routes share *b*-th node

Parameters:	
T	– planning horizon, that is the period during which all the deliveries must departure from the first nodes of their routes
fr_i	– the number of the deliveries to be scheduled for the i-th route
H_i	– fixed headway of the i-th route
t_{ib}	– travel time between the first node of the i-th route and the b-th node
w_b	– lower limit of the synchronization range in the b-th node
W_b	– upper limit of the synchronization range in the b-th node
M	– big number
Decision variables:	
X_{ip}	– the departure time of the p-th delivery of i-th route; time variable (non-negative, continuous)
Y_{ijbpq}	$Y_{ijbpq} = 1$, if the p-th vehicle of i-th route arrives at b-th node before the q-th vehicle of j-th route and the interval between arrivals is in the range $<w_b;\ W_b>$; otherwise $Y_{ijbpq} = 0$

Źródło: opracowanie własne [Gdowska i Książek 2015].

Source: own work [Gdowska and Książek 2015].

Table 2. Mixed-integer programming model for the cyclic delivery synchronization problem

Tabela 2. Model programowania całkowitoliczbowego mieszanego dla problemu synchronizowania cyklicznych dostaw

Objective functions:		
$\max \rightarrow \sum_{i \in I} \sum_{j \in I} \sum_{b \in B} \sum_{p \in F_i} \sum_{q \in F_j} Y_{ijbpq}$	$i, j \in I; b \in B; 1 \leq p \leq fr_i; 1 \leq q \leq fr_j$	(1)
Constraints:		
$X_{i,1} \leq H_i$	$i \in I$	(2)
$X_{i, fr_i} \leq T$	$i \in I$	(3)
$X_{i,p+1} - X_{ip} = H_i$	$i \in I, 1 \leq p \leq fr_i - 1$	(4)
$(X_{jq} + t_{jbq}) - (X_{ip} + t_{ibp}) \leq W_b + M * (1 - Y_{jibqp})$	$i, j \in I; b \in B; 1 \leq p \leq fr_i; 1 \leq q \leq fr_j$	(5)
$(X_{jq} + t_{jbq}) - (X_{ip} + t_{ibp}) \geq w_b - M * (1 - Y_{jibqp})$	$i, j \in I; b \in B; 1 \leq p \leq fr_i; 1 \leq q \leq fr_j$	(6)
$Y_{ijbpq} \leq 1 - Y_{jibqp}$	$i, j \in I; b \in B; 1 \leq p \leq fr_i; 1 \leq q \leq fr_j, <i, j, b> \in S^{ijb}$	(7)
$Y_{ijbpq} = 0$	$i, j \in I; b \in B; 1 \leq p \leq fr_i; 1 \leq q \leq fr_j, <i, j, b> \notin S^{ijb}$	(8)
$X_{ip} \in \{0, 1, \ldots T\}$	$i \in I, p \leq fr_i$	(9)
$Y_{ijbpq} \in \{0, 1\}$	$i, j \in I; b \in B; 1 \leq p \leq fr_i; 1 \leq q \leq fr_j$	(10)

Źródło: opracowanie własne w oparciu o model BTP [Ibarra-Rojas i Rios-Solis 2012, Gdowska i Książek 2015].

Source: own work based on the BTP model [Ibarra-Rojas and Rios-Solis 2012, Gdowska and Książek 2015].

RANDOM SEARCH ALGORITHM FOR THE CYCLIC DELIVERY SYNCHRONIZATION PROBLEM

Basing on the MIP model presented in the previous section a random search algorithm was developed as there was a need for a tool applicable for medium-sized and large-sized problems. Random heuristic search is a well-known abstract search method which is instantiated to particular search methods with remarkable success [Vose 1999].

Let N be the set of routes for which departure time of the very first vehicle have been *defined*. Let P^i denote the set of nodes belonging to the i-th route. Let s_i denote weight used for determining probability of choosing *i*-th route. The value of the *i*-th route's weight is computed as a number of nodes shared by the *i*-th route with other routes for which departure times of the very first vehicle have not been determined.

$$s_i = \sum_{j \in I, j \notin M, i \neq j} \left| P^i \cap P^j \right|, i \in I \tag{11}$$

Let d_b be the weight used for determining probability of choosing *b*-th node. The value of the *b*-th node's weight is computed as a number of routes sharing the *b*-th node.

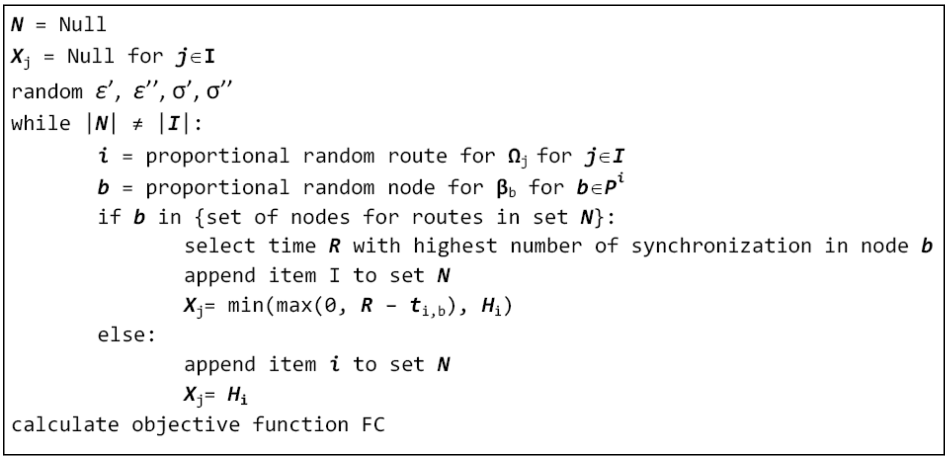
$$d_b = \sum_{j \in I} \left| \{b\} \cap P^j \right|, b \in B \tag{12}$$

For weights s_j and d_b we determined decision criteria, respectively, Ω_j and β_b, for which we proportionally chose a route or a node, respectively. Decision criteria Ω_j and β_b, were constructed using random parameters, ε' (ε'') and σ' (σ''). When parameter ε' (ε'') equals 0, probability of choosing the worst (lowest) values of weights for routes (nodes) equals 0 as well. When the value of parameter ε' (ε'') increases, probability of choosing route (node) with the lowest weight also raises. When the value of random parameter σ' (σ'') increases, it becomes more likely to choose a route (a node) of higher weight.

$$\Omega_j = \left(s_j - \min\left(s_j\right) + \varepsilon'\right)^{\sigma'}, j \in I \tag{13}$$

$$\beta_b = \left(d_b - \min\left(d_b\right) + \varepsilon''\right)^{\sigma''}, b \in B \tag{14}$$

Randomize search algorithm works until the departure time of the very first vehicle for every route is set. With respect to determined decision criteria Ω_j and β_b, respectively, route *i* and node *b* are randomly chosen. If chosen node *b* belongs to the certain number of routes (node *b* belongs at least to one route) for which the departure time of the very first vehicle has been determined already, the departure time of the very first vehicle of the chosen route *i* is determined, so that it is involved in as many synchronizations as possible. Otherwise, the departure time of the very first vehicle of the chosen route *i* equals the frequency of *i*-th route (H_i). The newly-developed random search algorithm is presented in the Figure 2.



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$N$ = Null
$X_j$ = Null for $j \in I$
random $\varepsilon'$, $\varepsilon''$, $\sigma'$, $\sigma''$
while $|N| \neq |I|$:
    $i$ = proportional random route for $\Omega_j$ for $j \in I$
    $b$ = proportional random node for $\beta_b$ for $b \in P^i$
    if $b$ in {set of nodes for routes in set $N$}:
        select time $R$ with highest number of synchronization in node $b$
        append item I to set $N$
        $X_j$= min(max(0, $R - t_{i,b}$), $H_i$)
    else:
        append item $i$ to set $N$
        $X_j$= $H_i$
calculate objective function FC
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Fig. 2. Scheme of the random search algorithm for cyclic delivery synchronization problem. Source: own work.

Rys.2. Schemat algorytmu losowego przeszukiwania dla problemu synchronizowania dostaw cyklicznych. Źródło: opracowanie własne.

COMPUTATIONAL EXPERIMENTS

Computations were conducted with a computer equipped with a processor Intel® Core™i3 2.20 GHz and 4 GB RAM. Random search algorithm was implemented in programing language Python 2.7. Computations were conducted using compiler belonging to PyPy package.

All the data sets were solved with the random search algorithm for the same ranges of random parameters ε' (ε'') and σ' (σ''); the random parameters were generated with the uniform distribution. The ranges of parameters are presented in Table 3.

Table 3. Ranges of parameters used in computational experiments

Tabela 3. Zakresy parametrów użytych w eksperymentach obliczeniowych

Parameter	Range
ε'; ε''	[0; 1]
σ'; σ''	[0; 10]

Źródło: opracowanie własne.

Source: own work.

For each data set the certain number of searches was performed with PyPy compiler using the newly-developed algorithm. Computation time was limited to 3 sec. (search was performed approximately 10^4 times). From the set of obtained solution the one with the highest number of synchronizations was selected. Detailed results for selected data sets are presented in Table 4. Solutions obtained with the newly-developed random search algorithm were compared with the optimal solutions obtained with the MIP model. Optimal solutions were obtained with solver GUROBI 6.0.4 with standard settings.

In Table 4 we present the selection of 15 data sets – the sets have different number of routes and nodes. It was possible to obtain optimal solutions for problems with 3 routes and 5 nodes. For problems with 20 routes were not solvable with solver GUROBI.

Table 4. Results of computational experiments

Tabela 4. Wyniki eksperymentów obliczeniowych

Data set	Number of nodes	Number of routes	Objective function – optimal	Objective function – heuristics	Optimization gap
1	7	3	45	34	0.32
2	7	3	62	59	0.05
3	7	3	51	40	0.28
4	7	3	73	64	0.14
5	7	3	87	73	0.19
1	10	5	112	101	0.11
2	10	5	194	186	0.04
3	10	5	257	218	0.18
4	10	5	270	259	0.04
5	10	5	203	184	0.10
1	30	20	----	2670	----
2	30	20	----	2748	----
3	30	20	----	2762	----
4	30	20	----	2407	----
5	30	20	----	2251	----

Źródło: opracowanie własne.

Source: own work.

The newly-developed random search algorithm for the cyclic delivery synchronization problem is considerably simple, e.g. it does not "learn" anything. This is why we cannot expect it to find optimal solutions for each data set; solutions found by the algorithm differ significantly from the optimal ones. Average optimization gap for problems with three and seven routes equals to 15 percent. We can assume that for problems with 20 routes we obtain results which are worse than the optimal ones by more than 15 percent. Nevertheless, the advantage of the introduced random search algorithm is short computing time which always ends with finding a feasible solution. Computing time does not get considerably longer as the problem size arises, so we are able to find solutions for problems which are too big for MIP methods.

CONCLUSIVE REMARKS

In this paper results obtained with the newly-developed randomize search algorithm for the cyclic delivery synchronization problem for selected data sets were presented. The heuristic was constructed with the aim of being as close as possible to the MIP model.

Therefore obtained results can be considered as satisfactory despite considerably big optimization gap. A huge advantage of the algorithm is very short time of searching for solutions, even for medium-sized problems, for which it is impossible to obtain optimal solution with the MIP model. The random search algorithm presented in this paper can be used for finding quickly the initial solution for other more advanced heuristic algorithms which will generate solutions with the smaller optimization gap.

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