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MANAGEMENT AND AUTOMATION OF ORGANIC FOOD DELIVERI SERVICES – A TRANSPORTATION MODEL

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In this paper an organic food delivery scheduling problem with time windows is presented. Described issue seems to be very important in the field of logistics in agriculture especially when organic food delivery to small shops, restaurants or customers' houses are considered. In this kind of services the frequency and number of deliveries are significantly high and every producer and client should be visited in the defined time window, therefore there is a strong need for coordination of deliveries' routes – every route begins with collecting goods from farms and subsequently, products are being delivered to customers. In this paper the organic food delivery scheduling problem is presented as a theoretical problem for which a mix integer programming model was developed. The model was employed for solving a small possible situation – computational experiment is described and results are reported. Moreover, directions for further research are suggested.

Transport, automation, delivery system, organic food, scheduling, MIP.

In this paper a delivery scheduling problem with time windows is presented. This issue seems to be very important in the field of logistics in agriculture especially when organic food delivery to small shops, restaurants or customers' houses are considered. Specific character of this kind of services results from number of reasons. First of all organic food is perishable, since no preservatives are utilized in this sector, therefore clients need to be supplied with small-sized lots of products, but frequency of deliveries is high. Secondly, producers of organic food are usually small- or medium-sized farms and they specialize in several products, therefore there is a need for numerous suppliers to satisfy customers' needs. Finally, every client has specific requirements on the delivery time, so that it is extremely important to define for each client a time window during which consecutive deliveries can arrive. Similarly, the producers define the earliest moment when the products are ready as well as the period during which the products remain fresh. A scheme of the organic food delivery problem is presented in Figure 1.

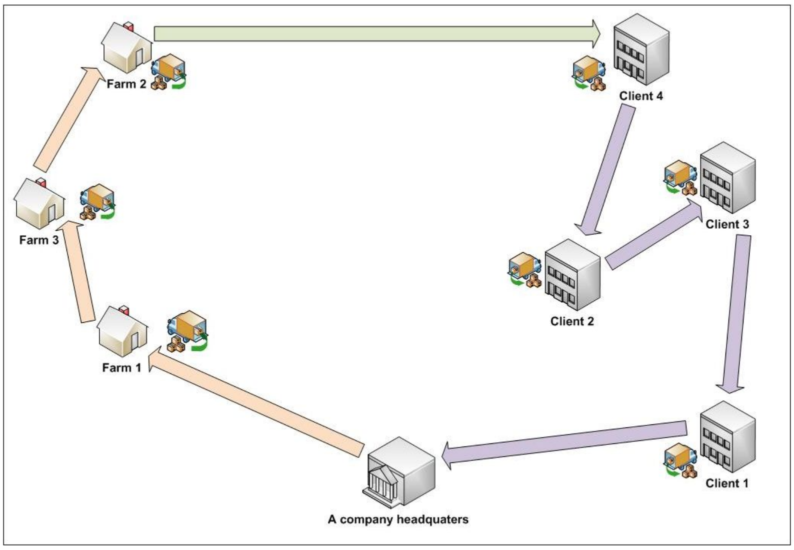

Fig. 1. Scheme of the organic food delivery problem

Due to the fact that the frequency and number of deliveries is significantly high and every producer and client should be visited in the defined time window, there is a strong need for coordination of deliveries' routes – the route begins with collecting goods from farms and subsequently, products are being delivered to customers. Certainly, also other specific conditions connected to both suppliers and customers should be taken into account in the structure of a delivery schedule.

In this paper the organic food delivery scheduling problem is presented as a theoretical problem for which a mix integer linear programming model was developed. The model was employed for solving a small possible situation – computational experiment is described and results are reported. The paper is organized as follows: the first paragraph is devoted to general description of the delivery scheduling problem. In the second paragraph a mixed integer linear programming model for organic food delivery scheduling problem is presented. Furthermore, utilization of the MIP model is presented and results obtained in computational experiments are reported. The final paragraph provides recapitulation of the presented problem and suggests directions for further research.

The purpose of research. The organic food delivery scheduling problem is, undoubtedly, an interdisciplinary one, since it combines issues from the area of logistics, agriculture and horticulture, operations research and computer science. For instance, the problem of delivery scheduling includes many aspects referred to transportation, scheduling and synchronization.

The group of transportation problem includes numerous problems; amongst others, vehicle routing problem [15, 2], travelling salesman problem [12, 16], scheduling problem [4] and timetabling problem [5, 7, 8, 9, 10]. Furthermore, the field of periodic deliveries is examined; amongst main problems in this area may be indicated: periodic service scheduling [11], minimizing the number of vehicles [3], seasonal deliveries [6], manufacturing and distribution scheduling with fixed delivery departure dates [13] or with time windows [12], cost optimization [14] and issues referring to quality, safety and sustainability of distribution [1]. It should be emphasized that specific organizational conditions of realizing deliveries are the main reason for variety of transportation models.

Another huge group of problems and, in consequence, mathematical models consists of organizational problems in manufacturing systems. The most important issues in supply chains are coordination and sequencing [19–27], especially in make-to-order environment [19–27]. As small-sized or medium-sized companies and production lots are the subject of research, coordination and synchronization seems to be the key factors of success, since they result in reduction of the lead time.

The purpose of research to which this paper is referred is to utilize mathematical models for transportation problems and manufacturing problems in order to develop a suitable mixed integer linear programming model for the organic food delivery scheduling problem described in the previous paragraph. Significant aspects of the problem are vehicle routing with time windows and sequencing of locations to visit (farms and clients).

Material and methods of research. A mixed integer programming model was developed for the organic food delivery problem. The model combines aspects of models mentioned in the previous paragraph.

In the model for the organic food delivery scheduling problem following sets, variables and parameters were utilized: S – set of suppliers (farms), C – set of clients (individuals, restaurants and organic food shops), and D – set of deliveries to be executed, where every delivery is understood as a route which begins with collecting products from every supplier and subsequently the stock is delivered to every client. A driver visits every supplier and every client only once on every route.

For each delivery several conditions are defined: r-th delivery should not be collected from the i-th supplier's farm earlier than LS_{ri} and it also should not be collected later than US_{ri}. Similar time window is defined for every client: r-th delivery should be brought to the k-th client's between LC_{rk} and UC_{rk}.

Furthermore, the distances between every pair of suppliers and clients are defined: TS_{ij} – travel time between the i-th supplier's farm and j-th supplier's farm, TSC_{ik} – travel time between the i-th supplier's farm and the k-th client's, TC_{kl} – travel time between the k-th client's and the l-th client's. It is assumed that time of collecting products from a supplier and time of bringing supplies to a client is irrelevant.

In this model variables of three types are utilized:

- arrival time of the r-th delivery: XS_{ri} – arrival time of the r-th delivery at i-th supplier's and collecting products the from the i-th supplier's farm and XC_{rk} – arrival time of the r-th delivery at the k-th client's and bringing supplies to the k-th client's;
- punishment for delay in collecting products from farms: ZS_{ri} yields the value 1, if the r-th delivery from the i-th supplier's farm is collected later than upper limit of the time window (US_{ri}), otherwise ZS_{ri} equals 0 and ZC_{rk} yields the value 1, if the r-th delivery is brought to the k-th client's later than upper limit of the time window (UC_{rk}), otherwise ZC_{rk} equals 0;

- task sequence variables: YC_{klr} yields the value 1, if the r-th delivery arrives at the k-th client's before the l-th client's, otherwise YC_{klr} equals 0 and $YS_{ijr} = 1$, if the r-th delivery is collected from the i-th supplier's farm before the j-th supplier's farm, otherwise YS_{ijr} equals 0.

Complete notation utilized in the model is presented in the Table 1.

Table 1. Notation. Source: own work

Sets:		
S	–	set of suppliers
C	–	set of clients
D	–	set of deliveries to be executed
Variables:		
XS_{ri}	–	(real variable) arrival time at i-th supplier's and collecting the r-th delivery from the i-th supplier's farm
XC_{rk}	–	(real variable) arrival time at k-th client's and bringing the r-th delivery to the k-th client's
ZS_{ri}	–	(binary variable) ZS_{ri} =1, if the r-th delivery from the i-th supplier's farm is collected later than upper limit of the time window during it should be collected, otherwise $ZS_{ri} = 0$
ZC_{rk}	–	(binary variable) (binary variable) ZC_{rk} =1, if the r-th delivery is brought to the k-th client's later than upper limit of the time window during it should be delivered, otherwise $ZC_{rk} = 0$
YS_{ijr}	–	(binary variable) $YS_{ijr} = 1$, if the r-th delivery is collected from the i-th supplier's farm before the j-th supplier's farm, otherwise $YS_{ijr} = 0$
YC_{klr}	–	(binary variable) $YC_{klr} = 1$, if the r-th delivery is brought to the k-th client's before the l-th client's, otherwise $YC_{klr} = 0$
$Tmax$	–	(integer variable) maximal time needed to fulfill a full cycle of delivery
Parameters:		
LC_{rk}	–	lower limit of the time window during which the r-th delivery should be brought to the k-th client's
UC_{rk}	–	upper limit of the time window during which the r-th delivery should be brought to the k-th client's
LS_{ri}	–	lower limit of the time window during which the r-th delivery should be collected from the i-th supplier's farm
US_{ri}	–	upper limit of the time window during which the r-th delivery should be collected from the i-th supplier's farm
TS_{ij}	–	travel time between the i-th supplier's farm and j-th supplier's farm
TSC_{ik}		travel time between the i-th supplier's farm and the k-th client's
TC_{kl}	–	travel time between the k-th client's and the l-th client's
M	–	big number

The mixed integer linear programming model for the organic food delivery problem with time windows is presented in Table 2. The organic food delivery problem presented in this paper is based on lot scheduling problems and vehicle routing problems. The optimization criterion is to minimize maximal route duration time (1a). In this situation we search for such a sequence of visited suppliers and clients that gives the shortest route duration – time between consecutive stops is forced to exceed the travel time between these locations as little as possible.

For this problem another optimization criterion can be utilized: to minimize the total punishment (1b). In this case route duration time is not forced to be as short as possible, so the travel time between two locations is limited mostly by the upper limits of time windows.

What is more, it seems to be possible combining both criteria mentioned above and to attribute wages to them (1c). However, this case was not a subject of research to which this paper is referred.

Table 2. Mixed integer linear programming model for the organic food delivery scheduling problem with time windows. Source: own work

Objectivity functions:		
$\min \; T_{\max}$		(1a)
$\min \sum_{i \in S} \sum_{k \in C} \sum_{r \in D} (ZS_{ri} + ZC_{rk})$		(1b)
$\min \alpha * \sum_{i \in S} \sum_{k \in C} \sum_{r \in D} (ZS_{ri} + ZC_{rk}) + \beta * T_{\max}$		(1c)
Subject to:		
$XS_{ri} \geq LS_{ri}$	$i \in S, r \in D$	(2)
$XC_{rk} \geq LC_{rk}$	$k \in C, r \in D$	(3)
$XS_{rj} + M*(1 - YS_{rij}) \geq XS_{ri} + TS_{ij}$	$i \in S, k \in C, r \in D$	(4a)
$XS_{ri} + M*YS_{rij} \geq XS_{rj} + TS_{iji}$	$i \in S, k \in C, r \in D$	(4b)
$XC_{rl} + M*(1 - YC_{rkl}) \geq XC_{rk} + TS_{kl}$	$i \in S, k \in C, r \in D$	(5a)
$XC_{rk} + M*YC_{rkl} \geq XC_{rl} + TS_{lk}$	$i \in S, k \in C, r \in D$	(5b)
$XS_{ri} \geq US_{ri} * (1 - ZS_{ri})$	$i \in S, r \in D$	(6)
$XC_{rk} \geq UC_{rk} * (1 - ZC_{rk})$	$k \in C, r \in D$	(7)
$XS_{ri} + TSC_{ik} \leq XC_{rk}$	$i \in S, k \in C, r \in D$	(8)
$\sum_{k} XC_{rk} + \sum_{i} XS_{ri} \leq T_{\max}$	$r \in D$	(9)
$XS_{ri} \geq 0$	$i \in S, r \in D$	(10)
$XC_{rk} \geq 0$	$k \in C, r \in D$	(11)
$ZS_{ri} \in \{0,1\}$	$i \in S, r \in D$	(12)
$ZC_{rk} \in \{0,1\}$	$k \in C, r \in D$	(13)
$YC_{rkl} \in \{0,1\}$	$k \in C, l \in C, r \in D$	(14)
$YS_{rij} \in \{0,1\}$	$i \in S, j \in S, r \in D$	(15)
$T_{\max} \geq 0$		(16)

The constraint (2) of the model prevents *r*-th delivery from arriving in the *i*-th farm before the earliest possible moment. Similarly the constraint (3) prevents *r*-th delivery from arriving in the *k*-th client too early.

The constraints (4a) and (4b) organize sequence of farms to visit during the *r*-th delivery route. If the *i*-th farm is to be visited before the *j*-th farm, then the earliest arrival time in the *j*-th farm has to be equal the arrival time in the *i*-th farm plus the travel time between i-th and j-th farms. Similar pair are constraints (5a) and (5b) which organize the sequence of clients to supply.

The system of deliveries is being punished for arriving in farms and clients' later than the upper limit of their time windows; constraints (6) and (7) punish r-th delivery for delayed arrival in i-th farm and k-th client's. Constraint (8) guarantees that r-th delivery route begins with collecting goods from farms and subsequently the products are delivered to clients. Finally, the constraint (9) serves to compute the maximal duration time of r-th route.

The results of research. With the model presented in the previous paragraph following computational experiment was conducted. A company supplies with organic food five clients, the products are provided by two farms. In the planning horizon two deliveries are to be scheduled. Detailed data utilized in the computational experiment are to be found in Table 3 and Table 4.

Table 3. Data utilized in the computational experiment. Source: own work

Farms	**Clients**	**Deliveries**	**Lower limits of time windows for Delivery 1**	**Upper limits of time windows for Delivery 1**	**Lower limits of time windows for Delivery 2**	**Upper limits of time windows for Delivery 2**
Farm 1		1,2	3	8	15	30
Farm 2		1,2	7	13	14	25
	Client 1	1,2	1	19	7	30
	Client 2	1,2	5	19	9	30
	Client 3	1,2	6	21	9	25
	Client 4	1,2	7	15	10	30
	Client 5	1,2	10	25	16	25

Table 4. Data utilized in the computational experiment – travel times. Source: own work

	Farm 1	**Farm 1**	**Client 1**	**Client 2**	**Client 3**	**Client 4**	**Client 5**
Farm 1	0	5	3	5	4	2	4
Farm 1	5	0	5	4	7	4	7
Client 1	3	5	0	2	5	4	6
Client 2	5	4	2	0	1	2	5
Client 3	4	7	5	1	0	3	4
Client 4	2	4	4	2	3	0	4
Client 5	4	7	6	5	4	3	0

The goal of the conducted computational experiment was to solve this problem with the GLPK Solver (GNU Linear Programming Kit ver. 4.3). Computations were conducted with a computer equipped with a processor Intel® Core™2 Duo 2.00 GHz and 4 GB RAM. Generated model contained: 168 constraints, 88 variables: number of integer variables – 86 (including binary variables), number of binary variables – 72. Searching for a solution lasted 0.1 sec; this amount of time was enough to obtain optimal solution. Obtained results are presented in Table 5.

Table 5. Obtained results. Source: own work

	Time of arrival in						
	Farm 1	Farm 1	Client 1	Client 2	Client 3	Client 4	Client 5
Delivery 1	3	8	16	14	21	12	25
Delivery 2	19	14	29	25	24	21	35

It is to be observed that both deliveries were conducted properly, since no arrival time exceeded the upper limit of time window. Furthermore, duration time of every route was as short as possible: duration time of Delivery 1 equalled 22 time units and duration time of Delivery 2 was 21 time units. It should be emphasised that for each delivery different sequence of visited locations was found. Nevertheless, for these data no punishment has to be assigned.

Conclusions

Basing on results obtained in the computational experiments it may be stated that the mixed integer linear programming model for the organic food delivery scheduling problem seems to be an accurate approach to searching for tools for strategic and operating planning in small-sized enterprises operating in the area of agriculture and horticulture. The main advantage of the model is the possibility to obtain optimal solution in very reasonable time. The model presented in this paper should be developed; objective function can be modified, further parts should be added as well as it should become more business-user friendly.

In this paper results obtained for a small network were presented. Continuation of research in this field is recommended, since there are many other aspects of perishable food delivery scheduling problem that were not taken into consideration in this problem. Amongst them are to be listed: costs of travel, waiting time and vehicle assignment problem.

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