Optimization of Operation Strategy for Collection Systems of Biohazard Wastes in Hospitals Based on Autonomous Robots: A Heuristic Approach

Tamás Bányai1*, Izteleuova Maral2, Béla Illés1, Ágota Bányai1 and Péter Tamás1

1University of Miskolc, Institute of Logistics, Miskolc-Egyetemváros, 3515, Hungary.
2Kazakh Academy of Transport and Communications named after M. Tynyshevaev, Almaty Shevchenko St., 97, 050012, Republic of Kazakhstan.

Authors' contributions

This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.

Article Information

DOI: 10.9734/AJRCOS/2020/v5i430142
(1) Dr. G. Sudheer, GVP College of Engineering for Women, India.
(2) Mgr. Volodymyr Polishchuk, Uzhhorod National University, Ukraine.
(1) Zineb Ibn-Majdoub Hassani, Sidi Mohamed Ben Abdellah University, Morocco.
Complete Peer review History: http://www.sdiarticle4.com/review-history/57957

Received 27 March 2020
Accepted 04 June 2020
Published 06 June 2020

ABSTRACT

The increasing rate of hospital admission led to increased volume of both municipal and biohazard wastes. The fourth industrial revolution opens up new perspectives to improve the conventional processes of hospitals and other institutions of health care systems. The application of new technologies integrated into the solutions of Industry 4.0 makes it possible to improve the efficiency of processes of hospitals not only in the field of medicine, but also in the field of other services, like logistics and supply chain. Within the frame of this article the authors are focusing on the development of new operation strategies for biohazard waste collection in hospitals using smart bins and autonomous waste collection vehicles/robots. The literature review helps to identify research gaps in the field of biohazard waste collection in hospitals. After that, the article describes the mathematical model of the waste collection system including smart bins, autonomous collection vehicles, users (patients and health professionals). The mathematical model has a time-based objective function, while time-, capacity- and safety-related constraints are also taken into consideration. The mathematical problem is an NP-hard problem; therefore, we use the non-linear
Keywords: Health care; industry 4.0; logistics; optimization; routing; waste collection.

1. INTRODUCTION

Health care institutions represent complex technical systems including processes, structures, a wide range of material and information flow, patients, and healthcare professionals. The daily routine of a hospital includes surgeries and other health services. For the successful implementation and realization of them it is essential to solve other tasks, among which we can find a huge number of logistic tasks. In the implementation of processes aimed at healing patients, the appropriate support of healthcare professionals and the increase of efficiency must be optimized. In addition to patient care, the quality of the operation of hospitals is also affected by the proper coordination and implementation of efficient measures and the implementation of logistical tasks. The efficiency of these logistics activities significantly affects the quality of patient care. Today, logistics is also a key factor in increasing efficiency and quality, as well as reducing costs. Developing and operating an integrated logistics system is a major challenge for hospitals. Health logistics deals with the planning, organization, management and control of the procurement, storage and use of human resources, vehicles and equipment, medical equipment, medical instruments, medicines, chemicals, medical devices and aids, equipment, and other consumables required for health care. That is, hospital logistics is the expedient and well-thought-out organization and implementation of hospital operations for patient care.

The literature includes a wide range of resources focusing on logistic problems of healthcare. We can find very valuable literature reviews and review articles focusing on various fields of healthcare logistics, like measuring the logistics performance of internal hospital supply chains [1], inventory and warehousing aspects in hospitals [2] or general logistic aspect in a hospital [3]. We can find a wide range of case studies from all over the world, for example a comparative case study of Danish and UK hospitals using benchmarking [4], an empirical analysis focusing on the impact of scheduling on drug supply in China [5], analysis of hospital-wide patient flow logistics [6], the analysis of improvement opportunities in patient logistics in Dutch healthcare system [7] or the analysis of innovation processes in hospitals [8].

The complex systems of healthcare logistics can be analyzed with various simulation approaches, like agent-based simulation [9] or discrete event simulation [10]. The stochastic environment and the uncertainties of a healthcare system can be taken into consideration with various stochastic decision-making models or Fuzzy models [11 and 12]. The lean philosophy can be applied not only for manufacturing companies, but lean concept, and lean six sigma is also important for healthcare institutions to optimize their processes and increase the efficiency of their services [13]. The logistic processes in a hospital include not only purchasing and distribution processes [14], but inverse or reverse aspects also must be taken into account [15]. Special areas of healthcare logistics include the following important research fields and applications of academic research results: optimization of trauma whole blood inventory [16], modeling and optimization of drug supply chains [17] or optimization of sterilization processes in a hospital focusing on logistic aspects [18].

The purpose of this study is to describe a new mathematical model to describe the collection process of biohazard wastes in healthcare environment and to demonstrate the importance the Industry 4.0 technologies in special service logistic systems. Based on the above-mentioned literature background [19-28] (see Fig. 1), the article is organized as follows. Chapter 2 presents the general structure of a possible integration of enterprise resource planning and hospital management system and focuses on the implementation opportunities of Industry 4.0 technologies, like digital twin or radiofrequency identification. The chapter describes the mathematical model of a biohazard waste collection systems based on smart bins and autonomous collection e-vehicles. The optimization model is based on time- and energy-based objective functions and takes capacity-, time- and energy-related constraints. Chapter 3 demonstrates the results of computational
The biohazard waste collection system includes $m$ smart bins and the capacity of these bins is given as $c_{bin}$. We can define various objective functions for this optimization problem. The first objective function is the minimization of transportation time, which can be described as follows:

$$L = L_1 + L_2 + L_3$$

where,

$L_1$ is the total length of the routes between the pool of autonomous waste collection vehicles and the first smart bin for biohazard waste in all $\tau$ collection routes, $L_2$ is the total length of the routes among the smart bins for biohazard waste in all $\tau$ collection routes, and $L_3$ is the total length of the routes between the last smart bin for biohazard waste and the collection storage for collected waste in all $\tau$ collection routes.
We can define the total length of the routes between the pool of autonomous waste collection vehicles and the first smart bin for biohazard waste as follows:

\[
L_1 = \sum_{\tau=1}^{p} l_{0,\tau,1}
\]

where, 
\(x_{ij}\) defines the assignment matrix of the smart bins to the selection routes and defines that the collection station \(j\) of route \(\tau\) is the smart bin with ID number \(x_{ij}\) and \(l_{0,\tau,1}\) is the length of route between the pool of autonomous collection vehicles and the first station of route \(\tau\).

The total length of the routes among the smart bins for biohazard waste in all \(\tau\) collection routes can be calculated depending on the decision variable \(x_{ij}\):

\[
L_2 = \sum_{\tau=1}^{p} \sum_{i=1}^{N_t-1} l_{x_{\tau,i},x_{\tau,i+1}}
\]

where,
\(N_t\) is the number of smart bins assigned to route \(\tau\) and \(l_{x_{\tau,i},x_{\tau,i+1}}\) is the length of transportation routes between smart bins assigned as station \(i\) and station \(i+1\) to route \(\tau\).

The total length of the routes between the last smart bin for biohazard waste and the collection storage for collected waste in all \(\tau\) collection routes can be calculated as follows:

\[
L_3 = \sum_{\tau=1}^{p} l_{x_{\tau,N_t},0}
\]

where,
\(l_{x_{\tau,N_t},0}\) is the length of transportation length between the smart bin assigned as last collection station and the collection storage for collected waste.

As second objective function we can define the minimization of energy consumption of
autonomous waste collection vehicles depending on the weight of loading and length of transportation routes:

\[ E = E_1 + E_2 + E_3 \] (5)

where,

\[ E_1 \] is the energy consumption of the vehicles between the pool of autonomous waste collection vehicles and the first smart bin for biohazard waste in all \( \tau \) collection routes, \( E_2 \) is the energy consumption of the vehicles among the smart bins for biohazard waste in all \( \tau \) collection routes, and \( E_3 \) is the energy consumption of the vehicles between the last smart bin for biohazard waste and the collection storage for collected waste in all \( \tau \) collection routes.

We can define the energy consumption of the vehicles between the pool of autonomous waste collection vehicles and the first smart bin for biohazard waste as follows:

\[ E_1 = \sum_{\tau=1}^{P} \sum_{i=1}^{N_\tau-1} l_{x_{\tau,i},x_{\tau,i+1}} \cdot q_{0,x_{\tau,1}} \cdot \vartheta \] (6)

where,

\( q_{0,x_{\tau,1}} \) defines the weight of load between the pool of autonomous collection vehicles and the first station of route \( \tau \) and \( q_{0,x_{\tau,1}} = q^* \), where \( q^* \) is the weight of the collection vehicle and \( \vartheta \) is the specific energy consumption.

The energy consumption of the vehicles among the smart bins for biohazard waste in all \( \tau \) collection routes can be calculated depending on the decision variable \( x_{\tau,1} \) and weight of load \( q_{i,j} \) as follows:

\[ E_2 = \sum_{\tau=1}^{P} \sum_{i=1}^{N_\tau-1} l_{x_{\tau,i},x_{\tau,i+1}} \cdot q_{x_{\tau,i},x_{\tau,i+1}} \cdot \vartheta \] (7)

where,

\( q_{x_{\tau,i},x_{\tau,i+1}} \) is the weight of load between smart bins assigned as station \( i \) and station \( i + 1 \) to route \( \tau \).

The energy consumption of the vehicles between the last smart bin for biohazard waste and the collection storage for collected waste in all \( \tau \) collection routes can be calculated as follows:

\[ E_3 = \sum_{\tau=1}^{P} l_{x_{\tau,N_\tau-1},0} \cdot q_{x_{\tau,N_\tau-1},0} \cdot \vartheta \] (8)

where,

\( q_{x_{\tau,N_\tau-1},0} \) is the weight of load between the smart bin assigned as last collection station and the collection storage for collected waste.

The optimal solution of the routing problem of waste collection vehicles is limited by the following constraints.

\textbf{Constraint 1:} the capacity of the autonomous waste collection vehicles is limited; therefore it is not allowed to exceed this upper limit:

\[ \forall \tau: \quad q_{x_{\tau,0},0} + \sum_{i=1}^{N_\tau-1} q_{x_{\tau,i},x_{\tau,i+1}} \leq q^\text{max}_v \] (9)

where,

\( q^\text{max}_v \) is the upper limit of the loading capacity of the autonomous waste collection vehicle.

\textbf{Constraint 2:} Using the digital process twinning and the collected data from smart bins, it is possible to forecast the weight and volume of the waste in the smart bins. The collection routes must be started in right time and the waste volume in each bin cannot exceed the maximum waste capacity. In the case of the first bin of the collection route, this constraint can be written as follows:

\[ \forall \tau: \quad q_{x_{\tau,1},0} \geq q_{x_{\tau,1},0} + \sigma_{x_{\tau,1}}(l_{0,x_{\tau,1}} \cdot \vartheta(0) + t_\tau) \] (10)

where,

\( q_{x_{\tau,1},0} \) is the upper limit of waste volume in bin assigned to the collection route \( \tau \) as first bin to be emptied, \( t_\tau \) is the starting time of collection route \( \tau \), \( \vartheta(0) \) is the velocity of the collection vehicle without loading, \( \sigma_{x_{\tau,1}} \) is the waste volume in the bin assigned as first bin to be emptied in collection route \( \tau \), \( \sigma_{0,x_{\tau,1}} \) is the forecasted waste collection increase rate of bin \( x_{\tau,1} \). In the case of the other bins of the collection route we can describe the same capacity related constraints regarding waste collection bins as follows:

\[ \forall \tau,s \leq N_\tau: \quad q_{x_{\tau,s},0} \geq q_{x_{\tau,s},0} + \sigma_{x_{\tau,s}}(l_{0,x_{\tau,1}} \cdot \vartheta(0) + \sum_{i=1}^{s-1} l_{x_{\tau,i},x_{\tau,i+1}} \cdot \vartheta(q) + t_\tau + l_{0,x_{\tau,1}} \cdot \vartheta(0) + \sum_{i=1}^{s-1} l_{x_{\tau,i},x_{\tau,i+1}} \cdot \vartheta(q)) \] (11)

where,

\( \vartheta(q) \) is the speed of waste collection vehicle depending on the weight of loading.

\textbf{Constraint 3:} It is not allowed to exceed the available energy of waste collection vehicle within a collection route:

\[ \forall \tau: \quad E_2 = \sum_{\tau=1}^{P} \sum_{i=1}^{N_\tau-1} l_{x_{\tau,i},x_{\tau,i+1}} \cdot q_{x_{\tau,i},x_{\tau,i+1}} \cdot e(l,q,\vartheta(q)) \] (12)
$e(l, q)$ is the specific energy consumption depending on the length of transportation route, weight of loading and speed.

The decision variable of this optimization problem is the assignment matrix of bins to collection routes and the scheduling matrix of waste collection operations.

Based on the above-mentioned mathematical model it is possible to find the optimal strategy of biohazard waste collection.

3. RESULTS AND DISCUSSION

Within the frame of this chapter, the computational results of a case study will be described to prove the above-mentioned mathematical model and to validate the efficiency of using Industry 4.0 technologies, like radio frequency identification or digital twin.

We can take into consideration the length of transportation routes among waste collection bins as Table 1 demonstrates (test data to verify the model). In the initial phase of the optimization the forecasted increase rate of the waste in bins is collected from the digital twin module and used as input data for the optimization (see Table 2).

Based on the increase rate and current waste volume it is possible to calculate the upper time limit before the smart bin must be emptied. Based on this information we can build the first cluster of bins, which must be emptied (see Table 3).

The autonomous waste collection vehicles have a specific energy consumption of 0.42 kW/LUm (LUm=loading unit multiplied with transportation distance in meter), and the net weight of the vehicle is 120 kg. Taking into consideration the above described input parameters and constraints; we can solve the routing problem with the nonlinear regression or evolutive option of Solver. Using the minimization of transportation length as objective function (Eq.1), the optimal routing of the first cluster is showing in Table 4.

Fig. 3 demonstrates the results of the routing in the first smart bin cluster. The blue gauge shows the waste level of the biohazard waste collection bins in the time of collection, while the green gauge shows the waste level of collection vehicle passing the current smart bin.
Table 1. Matrix of transportation routes

|   | 1   | 2   | 3   | 4   | 5   | 6   | 7   | 8   | 9   | 10  | 11  | 12  | 13  | 14  | 15  | 16  | 17  | 18  | 19  | 20  |
|---|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|
| 1 | 0.00| 83.2| 70.4| 46.1| 60.0| 54.4| 92.6| 72.0| 12.0| 45.1| 21.0| 28.0| 36.2| 63.5| 60.0| 23.0| 85.0| 42.0| 64.2| 75.0|
| 2 | 83.2| 0.00| 63.2| 40.0| 30.4| 72.1| 64.8| 24.3| 87.3| 59.4| 91.3| 56.8| 52.0| 48.3| 23.0| 80.0| 52.0| 41.2| 20.0| 44.7|
| 3 | 70.4| 63.2| 0.00| 63.2| 37.0| 20.0| 66.6| 38.9| 65.0| 25.6| 62.1| 48.9| 68.0| 16.0| 42.0| 84.8| 21.5| 53.8| 60.0| 20.0|
| 4 | 46.1| 40.0| 63.2| 0.00| 30.4| 60.0| 26.0| 39.4| 53.1| 44.0| 59.4| 25.9| 12.0| 48.3| 46.1| 40.0| 65.6| 10.0| 20.0| 54.4|
| 5 | 60.0| 30.4| 37.0| 30.4| 0.00| 42.0| 45.8| 12.0| 61.1| 29.0| 63.5| 32.0| 39.4| 21.0| 20.0| 64.2| 35.2| 23.8| 23.0| 24.1|
| 6 | 54.4| 72.1| 20.0| 60.0| 42.0| 0.00| 55.4| 48.9| 47.1| 16.0| 43.0| 38.9| 61.1| 25.6| 54.4| 72.1| 40.7| 50.0| 63.2| 35.7|
| 7 | 20.6| 64.7| 66.6| 26.0| 45.9| 55.4| 0.00| 57.4| 29.6| 41.6| 37.5| 17.6| 56.5| 65.3| 18.8| 76.5| 24.0| 45.1| 65.5| 65.1|
| 8 | 72.0| 24.3| 38.9| 39.4| 12.0| 48.9| 57.4| 0.00| 72.9| 72.9| 72.8| 38.2| 24.1| 21.9| 7.0| 75.5| 30.8| 34.5| 25.9| 21.0|
| 9 | 12.0| 87.3| 65.0| 53.1| 61.1| 47.1| 29.6| 72.9| 0.00| 41.0| 9.0| 30.4| 44.8| 60.6| 80.9| 35.0| 81.7| 47.1| 69.4| 72.5|
| 10| 45.1| 59.4| 25.6| 44.0| 29.0| 16.0| 41.6| 38.2| 41.0| 0.00| 40.0| 24.1| 45.6| 20.0| 45.1| 59.4| 40.7| 34.0| 48.3| 32.0|
| 11| 21.0| 91.3| 62.1| 59.4| 63.5| 43.0| 37.5| 75.0| 9.00| 40.0| 0.00| 35.0| 52.1| 60.0| 82.7| 44.0| 80.4| 52.5| 74.4| 72.0|
| 12| 28.0| 56.8| 48.9| 25.9| 32.0| 38.9| 17.6| 44.0| 30.4| 24.1| 35.0| 0.00| 23.0| 38.2| 52.0| 36.2| 59.5| 17.6| 39.4| 48.7|
| 13| 36.2| 52.0| 68.0| 12.0| 39.4| 61.1| 15.6| 49.6| 44.8| 54.1| 0.00| 54.1| 56.8| 28.0| 73.5| 15.6| 32.0| 62.2| 62.3|
| 14| 63.5| 48.3| 16.0| 48.3| 21.0| 25.6| 55.6| 24.1| 60.6| 20.0| 60.0| 38.2| 54.1| 0.00| 29.0| 74.4| 21.5| 39.4| 44.0| 12.0|
| 15| 80.0| 23.0| 42.0| 46.1| 20.0| 54.9| 85.3| 8.00| 80.8| 45.8| 82.7| 52.0| 56.8| 29.0| 0.00| 83.2| 29.0| 42.0| 30.4| 24.2|
| 16| 23.0| 80.0| 84.8| 40.0| 64.2| 72.1| 18.8| 75.5| 35.0| 59.4| 44.0| 36.2| 28.0| 74.4| 83.2| 0.00| 95.4| 41.2| 60.0| 84.8|
| 17| 85.0| 52.0| 21.5| 65.6| 35.2| 40.0| 76.5| 30.8| 81.7| 40.7| 70.0| 80.4| 59.5| 73.5| 21.5| 29.0| 95.4| 0.00| 58.0| 55.7| 11.3|
| 18| 42.0| 41.2| 53.8| 10.0| 23.8| 50.0| 24.0| 34.5| 47.3| 34.0| 52.0| 17.6| 15.6| 39.4| 42.0| 41.2| 58.0| 0.00| 22.3| 46.6|
| 19| 64.2| 20.0| 60.0| 20.0| 23.0| 63.2| 45.1| 25.9| 69.4| 48.3| 74.4| 39.1| 32.0| 44.0| 30.4| 60.0| 55.7| 22.3| 0.00| 45.6|
| 20| 75.0| 44.7| 20.0| 54.4| 24.1| 35.7| 65.5| 21.0| 72.5| 32.0| 72.0| 48.7| 62.3| 12.0| 22.4| 84.3| 11.3| 46.6| 45.6| 0.00|
Table 2. Increase rate of waste (LIR) and current waste volume in the smart bin

| BIN ID | LIR | CL | FF | CLE | CCW |
|-------|-----|----|----|-----|-----|
| 1     | 0.4 | 92 | 20 | 96  | 96  |
| 6     | 0.05| 94 | 120| 94.5| 190.5|
| 10    | 0.1 | 93 | 70 | 94  | 284.5|
| 3     | 0.2 | 85 | 75 | 87  | 371.5|
| 11    | 0.4 | 66 | 85 | 70  | 441.5|
| 5     | 0.1 | 68 | 320| 69  | 510.5|
| 12    | 0.05| 65 | 700| 65.5| 576  |

BIN ID: identification number of biohazard waste collection bin, LIR: Increase rate of waste computed by the digital twin module, CL: Current waste level in the bin, FF: Forecasted time when the waste is on maximum level in the smart bin, CLE: Current level of waste within the collection phase (the level is forecasted taking into account, that the required time of collection is less than the total time-span), CCW: cumulated waste volume in the first bin cluster.

Table 3. The first cluster of collection

| BIN ID | LIR | CL | FF | CLE | CCW |
|-------|-----|----|----|-----|-----|
| 0     | 36.24| 32.00| 37.00| 20.00| 16.00| 40.00| 21.00| 23.00|
| 1     | 32.00| 37.00| 20.00| 16.00| 40.00| 21.00| 23.00|
| 2     | 37.00| 20.00| 16.00| 40.00| 21.00| 23.00|
| 3     | 20.00| 16.00| 40.00| 21.00| 23.00|
| 4     | 16.00| 40.00| 21.00| 23.00|
| 5     | 40.00| 21.00| 23.00|
| 6     | 21.00| 23.00|
| 7     | 23.00|
| 8     | 23.00|

BIN ID: identification number of biohazard waste collection bin, RL: length of transportation route, Q: quantity of loading collected at the current smart bin in LU (loading unit), CCW: cumulated waste volume, QL: performance of material handling as a multiplication of transportation length and quantity of loading, CQL: cumulated performance of material handling, EC: energy consumption between the predecessor and current bin, CEC: cumulated consumption between the predecessor and current bin.

After scheduling the first cluster, we can compute the resulted new waste levels after finishing the collection in the first bin cluster and we can define the second cluster of bins to be emptied, as shown in Table 5. The starting time of the collection process in the second route can be defined as min\( (FP) - t_{ec} \) where \( t_{ec} \) is the estimated time of a collection route.

Using the minimization of transportation length as objective function (Eq. 1), the optimal routing of the second cluster is showing in Table 6.

Fig. 4 demonstrates the results of the routing in the second smart bin cluster. The blue gauge shows the waste level of the biohazard waste collection bins in the time of collection, while the green gauge shows the waste level of collection vehicle passing the current smart bin. This optimization algorithm can be repeated as an iterative process within the time span of the design and scheduling and the optimal routing can be determined to minimize the transportation time or energy consumption.

The materials handling operations, supply chain solutions and logistic processes are more and more important in the field of both production and services [29,30]. The services represent a special field of logistics operations because special directives, laws and rules must be taken into consideration. Health care systems belong to these special fields. The fourth industrial revolution makes it possible to apply new technologies in logistics related operations in health care systems. Within the frame of this article the authors highlighted the fact that Industry 4.0 technologies can improve the
efficiency of conventional health care-related logistic operations, but new models and design methods are required to optimize the new, complex processes. Health care-related logistic processes can be converted into cyber-physical processes, where radiofrequency identification, digital twin, cloud computing can be used. We can indicate analogues of the developed technology in other industries, such as the airports. Airports, like air cargo hubs and big international passenger airports produce waste volumes equivalent to those of small cities [31, 32] and therefore it is important to integrate Industry 4.0 technologies into the airport waste collection systems to improve their efficiency and security.

Table 5. The first cluster of collection

| BIN ID | LIR   | CL  | CLE  | CCW  |
|--------|-------|-----|------|------|
| 20     | 0.35  | 61.5| 96.5 | 96.5 |
| 15     | 0.35  | 60.5| 95.5 | 192  |
| 17     | 0.2   | 62  | 82   | 274  |
| 4      | 0.25  | 54.5| 79.5 | 353.5|
| 19     | 0.2   | 43  | 63   | 492.5|
| 13     | 0.25  | 35.5| 60.5 | 553  |

Abbreviations see below Table 3

Table 6. The routing solution of the first cluster using the minimization of transportation length as objective function

| BIN ID | 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 |
|--------|---|---|---|---|---|---|---|---|---|
| 16     | 20| 17| 15| 8 | 19| 4 | 13| 16|
| RL     | 84.38| 11.31| 29.00| 8.00| 25.94| 20.00| 12.00| 28.00|
| Q      | 96.50| 82.00| 95.50| 76.00| 63.00| 79.50| 60.50|
| CCW    | 10125.61| 2449.42| 5858.00| 1724.00| 5084.68| 3660.00| 2394.00| 5054.00|
| QL     | 12575.03| 18433.03| 20157.03| 25241.71| 28901.71| 31295.71| 36349.71|
| CQL    | 5281.51| 7741.87| 8465.95| 10601.52| 12138.72| 13144.20| 15266.88|

Abbreviations see below Table 4

Fig. 4. Results of routing in the second cluster
4. CONCLUSION

The added value of the paper is the modelling of a biohazard waste collection system based on smart bins and autonomous waste collection vehicles. The scientific contribution of this paper for researchers in this field is the mathematical model, which includes a time and energy consumption-based objective functions and constraints focusing on capacity and available energy for e-vehicles performing collection operation. The results can be generalized because the model can be applied for various collection systems using smart bins and smart vehicles. Managerial decisions can be influenced by the results of this research because the results of the above described optimization and scenario have a great impact on waste management strategy.

ACKNOWLEDGEMENTS

The research was carried out as part of the Erasmus+CBHE 585967-EPP-1-2017-1-DE-EPPKA-CBHE-JP-PRODLOG project entitled “Development of a Bologna-based Master Curriculum in Resource Efficient Production Logistics/ProdLog”. The research reported here was carried out as part of the EFOP-3.6.1-2016-00011 Younger and Renewing University – Innovative Knowledge City –Institutional development for the University of Miskolc aiming at intelligent specialization” project implemented in the framework of the Széchenyi 2020 program. The realization of this project is supported by the European Union, co-financed by the European Social Fund.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

REFERENCES

1. Moons K, Waeyenbergh G, Pintelon L. Measuring the logistics performance of internal hospital supply chains - A literature study. OMEGA Int J Manag Sci. 2019;82:205-217. DOI:10.1016/j.omega.2018.01.007.
2. Volland J, Fligener A, Schoenefelder J, Brunner JO. Material logistics in hospitals: A literature review. OMEGA Int J Manag Sci. 2017;69:82-101. DOI:10.1016/j.omega.2016.08.004.
3. Oliveira RP, Reis AD, Castro AD. Hospital logistics: a synthesis of the art state. Gestao E Desenvolvimento. 2018;15(1):205-231. DOI:10.25112/rgd.v15i1.1276
4. Feibert DC, Andersen B, Jacobsen P. Benchmarking healthcare logistics processes - a comparative case study of Danish and US hospitals. Total Qual Manag Bus Excell. 2019;30(1-2):108-134. DOI:10.1080/14783363.2017.1299570.
5. Law KMY. How schedule issues affect drug logistics operations: an empirical study in hospitals in China. Ind Manage Data Syst. 2016;116(3):369-387. DOI:10.1108/IMDS-03-2015-0091.
6. Villa S, Prevestini A, Giusepi I. A framework to analyze hospital-wide patient flow logistics: Evidence from an Italian comparative study. Health Policy. 2014;115(2-3):196-205. DOI:10.1016/j.healthpol.2013.12.010.
7. van Lent WAM, Sanders EM, van Harten WH. Exploring improvements in patient logistics in Dutch hospitals with a survey. BMC Health Serv Res. 2012;12:232. DOI:10.1186/1472-6963-12-232.
8. Su SII, Gamgelaard B, Yang SL. Logistics innovation process revisited: insights from a hospital case study. INT J Phys Distr Log Manag. 2011;45(5-6):577-600. DOI:10.1108/09600031111147826.
9. Fragapane GI, Zhang C, Sgarbossa F, Strandhagen JO. An agent-based simulation approach to model hospital logistics. Int J Simul Model. 2019;18(4):654-665. DOI:10.2507/JSIMM18(4)497.
10. Rupnik B, Nardin R, Kramberger T. Discrete Event Simulation of Hospital Sterilization Logistics. Tehnicki Vjesnik-Technical Gazette. 2019;26(5):1486-1491. DOI:10.17559/TV-20180614102011.
11. Ahmadi E, Masel DT, Hostetler S. A robust stochastic decision-making model for inventory allocation of surgical supplies to reduce logistics costs in hospitals: A case study. Oper Res Health Care 2019;20:33-44. DOI:10.1016/j.orhc.2018.09.001.
12. Liu M, Zhang Z. Logistics planning for hospital pharmacy trusteeship under a hybrid of uncertainties. TRANSP Res E. 2017;101:201-215. DOI:10.1016/j.tre.2017.02.006.
13. Teng J, Wang JH, Teng L. Application and evaluation of lean logistics management in first affiliated hospital of Xinjiang Medical...
14. Lechuga GP. Optimal logistics strategy to distribute medicines in clinics and hospitals. J Math Ind. 2018;8:2. DOI:10.1186/s13362-018-0044-5.

15. Yui KP, dos Reis CCC, Moro MF, Flores SD, Garza AYM, Berghauer NAC, et al. Parameters involved in the internal reverse logistics of a hospital pharmacy. Braz J Oper Prod Manag. 2017;14(3):318-326. DOI:10.14488/BJOPM.2017.v14.n3.a5.

16. Phan-Tang M, Fang A, Miranda DM, Rioveros J, Stalcup I, McGonigle AM, et al. Logistics of Managing a Trauma Whole Blood Inventory in a Hospital Setting. Transfusion. 2019;59:68.

17. Kees MC, Bandoni JA, Moreno MS. An Optimization Model for Managing the Drug Logistics Process in a Public Hospital Supply Chain Integrating Physical and Economic Flows. Ind Eng Chem Res. 2019;58(9):3767-3781. DOI:10.1021/acs.iecr.8b03968.

18. van de Klundert J, Muls, P, Schadd M. Optimizing sterilization logistics in hospitals. Health Care Manag Sci. 2008;11(1):23-33. DOI:10.1007/s10729-007-9037-4.

19. Feibert DC, Jacobsen P. Factors impacting technology adoption in hospital bed logistics. Int J Log Manage.. 2019;30(1):195-230. DOI:10.1016/j.ijlm.2017-00043.

20. Xuan Q, Yu YW, Chen JY, Ruan ZY, Fu Z, Lv ZC. Robustness Analysis of Bipartite Task Assignment Networks: A Case Study in Hospital Logistics System. IEEE Access. 2019;7:58448-58494. DOI:10.1109/ACCESS.2019.2914258.

21. Liu TZ, Shen AZ, Hu XJ, Tong GX, Gu W, Yang SL. SPD-based Logistics Management Model of Medical Consumables in Hospitals. Iran J Public Health. 2016;45(10):1288-1299.

22. Aguilar-Escobar VG, Garrido-Vega P, Gonzalez-Zamora MD. Applying the theory of constraints to the logistics service of medical records of a hospital. Eur Res Manag Bus Eco. 2016;22(3):139-146. DOI:10.1016/j.iiedee.2015.07.001.

23. Majchrzak-Lepczyk J, Bober B. Selected aspects of the logistics network of public hospitals in the competitive market of health services. Logforum. 2016;12(4):247-267. DOI:10.17270/J.LOG.2016.4.6.

24. Calderon CAA, Mohan ER, Ng BS. Development of a hospital mobile platform for logistics tasks. Digital Comm Networks. 2015;1(2):102-111. DOI:10.1016/j.dcan.2015.03.001.

25. Bloss R. Mobile hospital robots cure numerous logistic needs. Ind Robot Int J. 2011;38(6):567-571. DOI:10.1108/01439911111179075.

26. Yasuda N. Hospital logistics system "MegaOak-M3". NEC Techn J. 2008;3(3):98-100.

27. Lapierre SD, Ruiz AB. Scheduling logistic activities to improve hospital supply systems. Comput Oper Res. 2007;34(3):624-641. DOI:10.1016/j.cor.2005.03.017.

28. Maruster L, Jorna RJ. Which kind of knowledge is suitable for redesigning hospital logistic processes? Lect Notes ArtifIntelli. 2005;3581:400-405.

29. Tamás P, Tollár S, Illéss B, Bányaı T, Bányaı A, Skapinyecz R. Decision Support Simulation Method for Process Improvement of Electronic Product Testing Systems. Sustainability. 2020;12(7):3063. DOI:10.3390/su12073063.

30. Ágárdi A, Kovács L, Bányaı T. Two-Echelon Vehicle Routing Problem with Recharge Stations. Transp Telecom. 2019;20(4):305-317. DOI:10.2478/tti-2019-0025.

31. Pitt M, Brown A, Smith A. Waste management at airports. Facilities. 2002;20(5-6):198-207.

32. Pitt M, Smith A. Waste management efficiency at UK airports. J Air Transp Manag. 2003;9(2):103-111.