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LAYOUT OPTIMIZATION OF A MULTI-CENTRE DISTRIBUTION MODEL

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Abstract: Supply chain planning is becoming increasingly important today, as it is essential for efficient operations to design supply chains that are flexible, sustainable, highly available and able to respond quickly and efficiently to dynamically changing customer needs, while operating cost-effectively. When designing supply chains, it is important to consider not only the investment cost but also the operational cost. This requires the most accurate forecasting of future supply chain needs. In this paper, the authors present a new method for the optimal design of a multicentre distribution network, which uses evolutionary optimisation and Monte Carlo simulation to determine the optimal distribution network structure in an arbitrary geographical area. The design takes into account investment and operational costs, with particular emphasis on the question of how to estimate the average transportation distances in a distribution network with an unknown structure.

Keywords: *facility location planning, optimization, logistics, transportation cost, investment cost*

1. INTRODUCTION

The design of material flow systems is an integrated engineering task that requires the simultaneous implementation of several design tasks in order to achieve an efficiently functioning system. This is particularly true for supply chains with a large geographical coverage, such as distribution networks. The integrated design of material flow systems includes route planning, facility location, scheduling, capacity planning, reliability calculations, queuing and the planning of packaging and unit load optimization tasks. To solve these planning tasks, a number of optimisation methods are available, some of which are analytical, others are heuristic or metaheuristic. The application of these design methods is determined by the complexity of the design problem to be solved.

Supply chains have changed dramatically in the wake of the pandemic, with the need to design flexible supply chains that can respond quickly to changes in customer demand and changes in supply chain structure, for example, a mechatronics assembly plant that needs to ensure the supply of parts following the loss of a supplier in the Far East. To achieve these flexible supply chains, a supply chain structure that is flexible enough to accommodate change with maximum efficiency and with minimum redundancy is needed to ensure continuous, long-term operation. In the case of distribution networks, this is particularly important, as a large number of customers need to be served with high reliability.

In this paper, the authors investigate how to design an optimal distribution network structure that is optimal in terms of both investment cost and operation cost, while at the same time being able to define a supply chain structure that can maximise profitability in an arbitrary geographical area. To this end, the authors first briefly summarise the progress made in the field of deployment planning and then present an approach that can be used to

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support the planning of an optimal distribution network by solving it using anintuition, evolutionary algorithm and Monte Carlo simulation.

2. LITERATURE REVIEW

Within the frame of this chapter, we are summarising the research results in the field of facility location. This section includes both descriptive and content analysis. Within the frame of the literature review, we have used Scopus to identify the most important scientific results in the field of facility location.

Firstly, the relevant terms must be defined. In this first crucial phase we have chosen a simply keyword: facility location to find a wide range of articles to perform a descriptive analysis of articles. Initially, 2551 articles were identified. Our search was conducted in March 2023; therefore, new articles may have been published since then.

As Fig. 1 shows, the facility location has been researched in the past 50 years. The first article in this field was published in 1968. The number of published papers focusing on facility location in supply chains and in-plant facility location has been increased in the last years; it shows the importance of this research field.

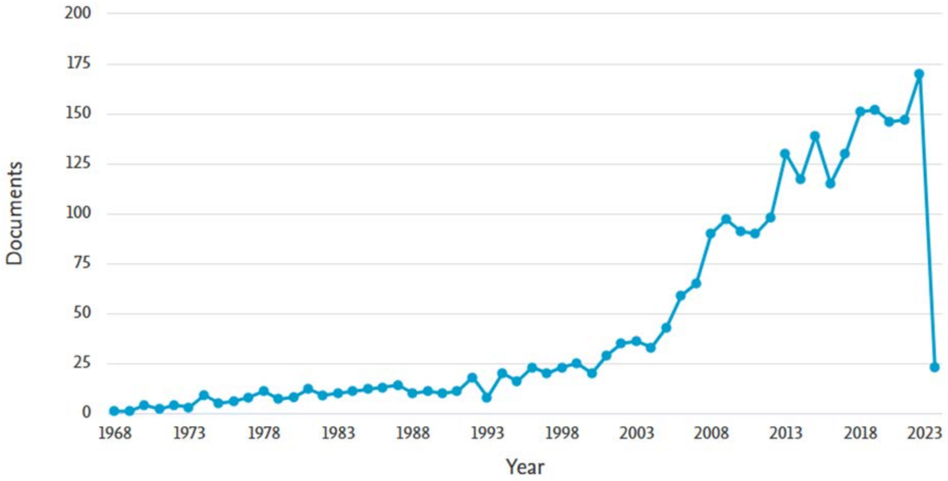

Figure 1. Published articles per year in the field of facility location resulted by a Scopus search (Source: www.scopus.com)

We can analyse the distribution of published articles per year and per source, as shown in Fig. 2.

It can be seen, that a wide range of articles in the field of facility location has been published in five scientific journals: Computers and Operations Research, Computers and Industrial Engineering, Annals of Operations Research, European Journal of Operational Research and Lecture Notes in Computer Science. The title and the main topic of these scientific journals shows, that the facility location is a complex engineering problem, its solution must be supported by state-of-the-art algorithms, methods and tools.

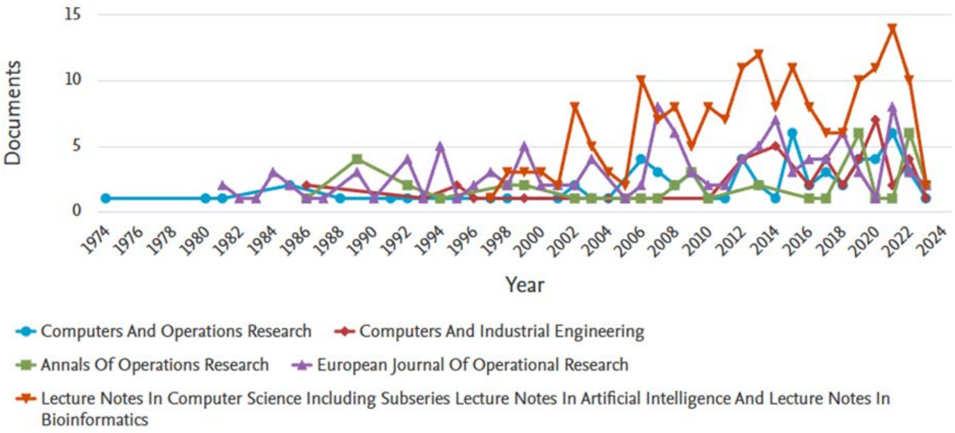

Figure 2. Published articles per year per source in the field of facility location resulted by a Scopus search (Source: www.scopus.com)

Fig. 3 shows the distribution of articles by the authors, publishing a huge number of articles. It can be seen, that 10 authors have been published 15 or more articles in the field of facility location, which shows, that there is a worldwide research expert group in the field of facility location.

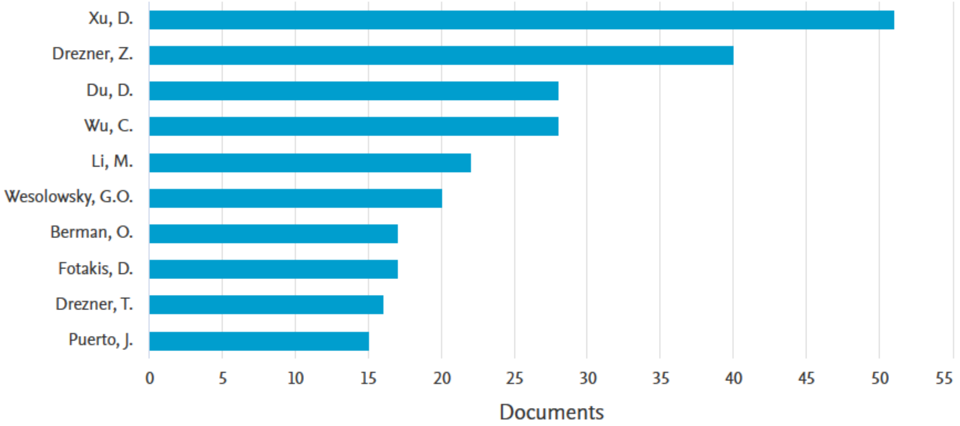

Figure 3. Published articles per authors in the field of facility location resulted by a Scopus search (Source: www.scopus.com)

As Fig. 4 shows, the affiliation of the most prolific authors is very different, including universities and research institutes in Asia, Europe and Amerika.

Most of the research results have been published in journal articles, but a significant number have been published in conference proceedings and books, as shown in Fig. 5. There are also the occasional abstracts, reviews, editorial, erratumes, notes and short surveys.

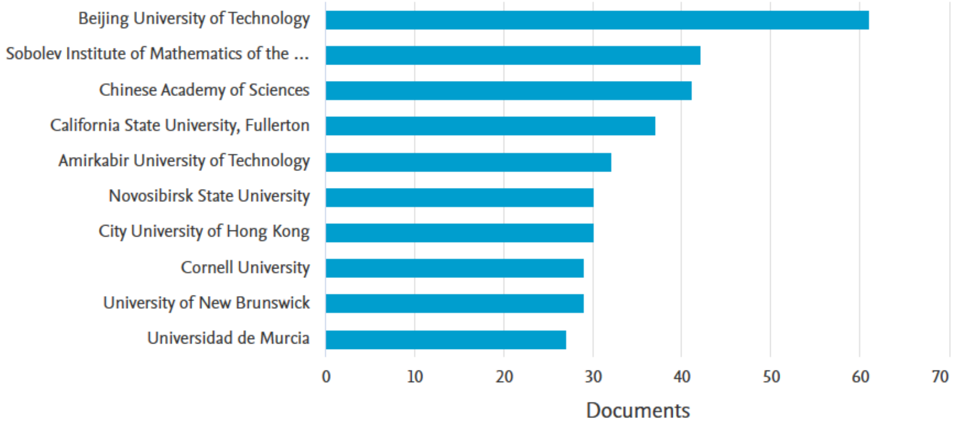

Figure 4. Published articles per affiliation of authors in the field of facility location resulted by a Scopus search (Source: www.scopus.com)

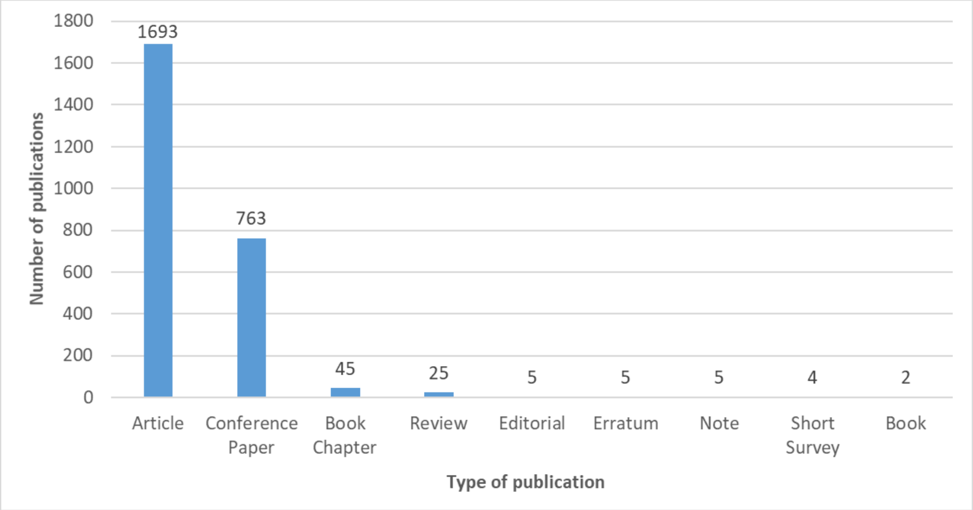

Figure 5. Published articles by type in the field of facility location resulted by a Scopus search (Source: www.scopus.com)

The analysis of the subject area of research works shows (see Fig. 6), that the ten most important subject area in the Scopus are the followings: computer science, mathematics, engineering, decision sciences, business and management, social sciences, environmental sciences and economics.

These subject areas highlight the importance of multidisciplinary approach in facility location because they are focusing on the following aspects:

- Computer science: facility location can represent NP-hard optimisation problems, and NP-hard optimisation problems can be solved using heuristic and metaheuristic algorithms using computers;

- Mathematics: the design of facility location problems must be supported by mathematical models including objective functions of optimisation, constraints and decision variables.
- Engineering: logistics is the integration of material flow and information flow, therefore the design of logistics systems must integrate both system or process design and design of resources in the logistics processes, for example design of material handling machines or choosing suitable transportation vehicles in the distribution system.
- Decision sciences: supply chains have three important levels: strategy, tactics and operational level. Decisions of these three levels must be supported by using state-of-the-art optimisation methods and tools.
- Business and economics: the cost efficiency is the core problem of supply chain solutions, therefore business and economics sciences are unavoidable to design and operate an efficient supply chain.
- Environmental sciences: the sustainability plays and important role in the design and operation of supply chain solutions, because energy efficiency and greenhouse gas emission is a crucial aspect of today’s logistics solutions.

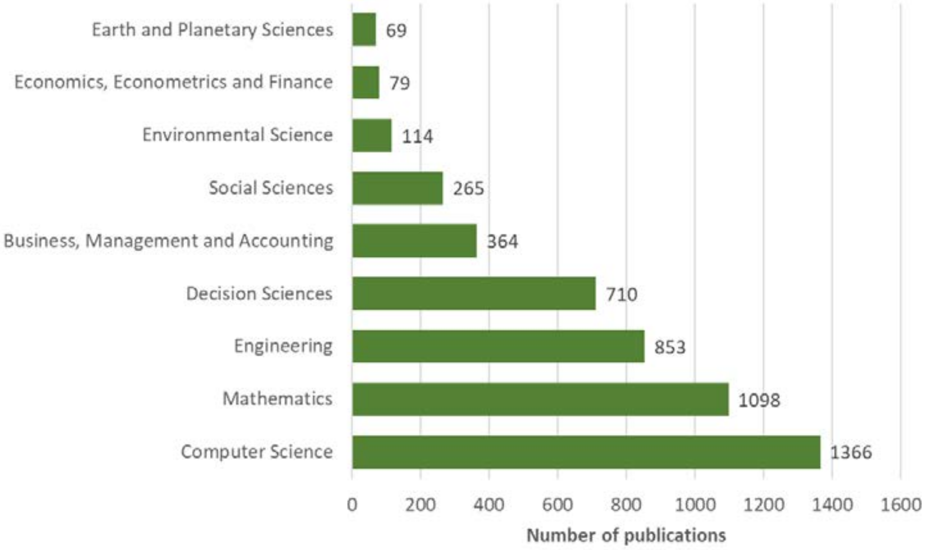

Figure 6. Published articles by subject area in the field of facility location resulted by a Scopus search (Source: www.scopus.com)

The next phase of the literature review is the content analysis, where the initial articles are filtered using additional keywords of Scopus. In our cases we have used the following keywords in the titles, abstract and keywords of articles: facility location, cost, logistics, optimisation. This search lead to 37 related articles. These articles are analysed within the frame of the content analysis.

The facility location is important not for small and medium companies but also multinational companies, company networks and company chains [1]. As a multi-cycle and multi-echelon location-routing problem for integrated reverse logistics shows, the integrated design of supply chain solutions is very important. The design tasks of supply chain solutions can be taken into consideration both sequential and parallel [2]. The integration of location and routing problems is demonstrated in [3], where the authors show a new approach to solve the problems of recharging of electric vehicles in supply chains including mixed backhauls and recharging strategies. Same problems are discussed by Agárdi et al., showing the solution of a two-echelon vehicle routing problem with recharge stations using metaheuristic algorithms [4]. In the case of complex problems, machine learning is a suitable way to solve optimisation problems, as in the case of a Brazilian disaster datasets are described. In this research work diverse humanitarian logistics operations are optimised in the disaster area [5]. Uncertainties are influencing humanitarian logistics operations, therefore planning for relief distribution, victim evacuation, redistricting and service sharing under uncertainty is a critical influencing factor of extreme-dynamical humanitarian logistics supply chains [6]. A robust neutrosophic fuzzy-based approach shows, how reliable facility location and routing decisions can be integrated for disaster relief under fairness and aftershocks concerns [7]. This research demonstrates the influence of capacity of emergency centres (warehouses or distribution centres) on the total cost and operation time. As a multi-objective model for the green capacitated location-routing problem shows, not only costs, but also other soft objectives, such as drivers' satisfaction and time window with uncertain demand can be taken into consideration 8]. Shared economy significantly changes the resource allocation. As the solution of a two-echelon multi-period location routing problem with shared transportation resource shows, location routing problems can be optimised using multi-objective functions focusing on operation cost and transportation efficiency in the case of resource sharing models [9,10]. The optimization of drugs delivery routes through location routing problem demonstrates, that due to a reduction of company sales volume, a delivery routes re-planning is required to optimize the operation cost, while the structure of warehouses in the supply chain must be also changed to optimize the total costs including transportation and warehousing cost [11]. Other interesting approach focuses on the unit-dose drug distribution systems in the case of small hospitals, where these small hospitals have to share the automatic distribution systems for economic reasons, therefore the optimisation of the structure of the drug supply chain process is a very sensitive issue from both cost and reliability point of view [12]. The location of emergency facilities and the routing of their service trucks is an important optimisation task in the field of emergency logistics. A sustainable multi-depot emergency facilities location-routing approach focuses on the problems of uncertain information and solve the location-routing problem with consideration of travel time, emergency relief costs and GHG emission [13].

Industry 4.0 technologies can be used to support the operation of supply chains in many fields including the FMCG sector [14], the automotive industry [15] and the packaging logistics [16]. Geoinformation systems can be used to improve the efficiency of facility location and routing problems [17]. It means, that Industry 4.0 technologies are unavoidable in the design and operation of different supply chain solutions. These technologies are also important in in-plant facility location problems, where the design and operation of in-plant processes includes the selection of material handling equipment [18], the comparison of the different material handling solutions [19], and the process-based design planning of in-plant material handling [20].

The design of drone delivery services represents a special type of routing and facility location problems. The general model of this problem includes a truck located at a central depot, and some possible drone stations, and a set of customer locations. The optimisation of this supply problem can be solved using mixed integer linear programming [12], but drone-based delivery problems can also be solved using branch and bound algorithm [22] and different heuristics [23].

Facility location is also a major issue in the case of leisure attractions, such as in the case of coastal tourist attraction, where the location of logistics centres significantly increases the transportation cost, therefore its optimisation is important [24]. Another research work in the field of tourist attraction-related logistics focuses on the capacitated facility location and allocation problems with uncertain demands [25]. Facility location problems can be defined as hub network problems. In this case hubs can serve as switching points to consolidate and route traffic [26]. A very special field of multi-depot facility location problems is represented by underground logistic systems. A genetic algorithm based optimisation approach shows, that the integrated facility location and vehicle routing problems can also be solved in the case of a bidirectional flow in an underground network [27]. The integrate approach has no limits. It is also possible to integrate more than two design tasks into a model, for example facility location, vehicle routing and inventory optimisation can also be integrated, as a case study shows in the field of perishable product supply chain [28]. Xie and Ouyang have studied the optimisation of spatial layout of transhipment facilities and the corresponding service regions on an infinite homogeneous plane and demonstrated the potentials of analytical methods [29].

As Fig. 7 shows, the solution methods of facility location related optimisation problems include a wide range of algorithms: particle swarm optimisation [2,9], time-dependent forward dynamic programming algorithm [3], arbitrary insertion [4], genetic algorithm [4,8,28], machine learning [5], Fuzzy set [6,7], progressive hedging algorithm [8], branch and bound [22], grey wolf optimisation [24], nondominated sorting genetic algorithm [25], simulation-based genetic algorithm [13], genetic algorithm with migration operation [27], distributive algorithms [30], clustering [31], analytical methods [29], ant colony optimisation [32], Lagrangian relaxation [33] and software tools [34].

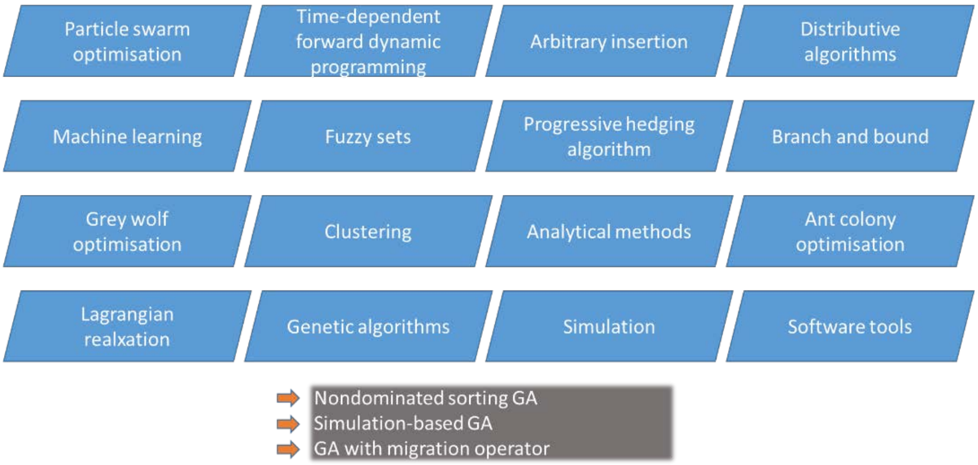

Figure 7. Solutions algorithms of facility location problems

As Fig. 8 summarises, the application fields of facility location problems includes reverse logistics [2,35], electric vehicle-based supply solutions [3,4], natural disasters and emergency situations [5,6,7,13,36], car sharing systems [9,10], drug delivery [11,12], drone-based delivery [21-23], tourist logistics [24,25], city logistics [27], perishable product supply chain [28], explosive waste management [37], relief logistics [38], postal services [39], cylinder gas distribution [40], soybean export [41], aircraft routing [42], terminal location and ship routing [43] and defence courier service [44].

Figure 8. Application fields of facility location

3. THE PROBLEM AND THE MODEL

When we are investigating places to build manufacturing or supporting structures and buildings there are settlements and locations that exist, not to mention the geological features of the area. These can be included or excluded in our optimization process, which can significantly influence our search for the perfect location in our structure(s). In most cases, these locations decrease our runtime of calculation because they decrease the number of potential locations of objects. But sometimes these can be distracting, because we need a fresh calculation from the initial state of the process, and then put our prediction into real planning. Based on predictions, we need to build logistic centers in a square area. Each logistic center can fulfill all demands of partners, but more centers can perform the fulfillment more efficient (less time and less distances). Each transport is a direct transport. The main design tasks of this supply problem is to compute the optimal number and location of these centers. There are 3 types of cost: building cost (C_b), operational cost (C_o) and transportation cost (C_t). The equations to approximately calculate the costs are the followings:

$$C_b + C_o + C_t \rightarrow min. \tag{1}$$

$$C_b = n_b * \left(c_b^f + \frac{c_b^s}{n_b} \right) \tag{2}$$

$$C_o = n_b * t_p * \left(c_o^f + \frac{c_o^s}{n_b} \right) \tag{3}$$

$$C_t = L_a * 2 * t_p * n_t * c_t \tag{4}$$

where C_b is the total building cost, C_o is the total operation cost of the project period, C_t is the total transport cost of the project period, n_b is the number of centres, t_p is the project period in years, c_b^f is the fixed cost of building a centre, c_b^s is the shared cost of building centres, c_o^f is the annual fixed cost of operating a centre, c_o^s is the annual shared cost of operating centres, L_a is the average distance the partners can be from logistic centres, n_t is the number of annual forecasted delivery and c_t is the transportation cost per km.

In the cost calculations, we use fixed and shared costs. This is a big oversimplification on our side. In reality, the costs are calculated in a much more complex level, but there are also fixed costs that must be taken into consideration in each location and shared costs are related to the sizes and designs. These dimensions here are derived from the number of deliveries as a simple weighting basis.

4. CASE STUDY

In this case study based on the problem and the model, all the costs and numbers are given, except the average distance. We have to estimate it from the size of the area, which is a square with 100km on each side. The parameters are shown in Table I. We propose 3 methods for the calculation of the length of average distances.

Table I.

Initial parameters

Parameter	Value	Parameter	Value
Area	10000 km2	Fixed cost of operation	0.25MEUR
Project period	5 years	Annual fixed operation cost	1MEUR
Fixed cost of building	10MEUR	Annual forecasted delivery	30000 deliveries/year
Shared cost of building	5MEUR	Transportation cost	5 EUR per km

4.1. Solution 1: Averaging the most extreme distances

When we examine a problem visually like in Fig. 9., we can see that we have some important statements.

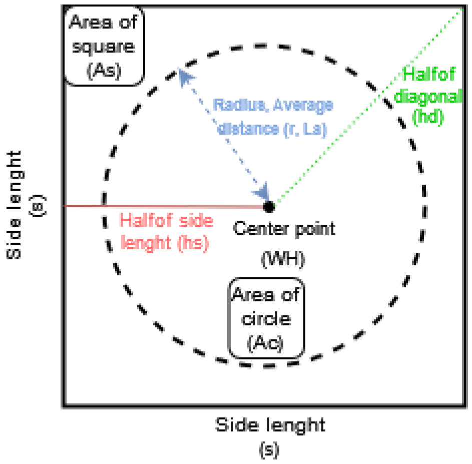

Figure 9. The area and location of one warehouse

When we need to install 1 centre and the locations of our customers are not specified, we need to put our centre in the middle of the square, because that is the most balanced point. We can reach every other point with the minimum travelled distance from here. If we look this task with a geometric focus, there are some important lines in the picture. The half of the diagonal of the square is the farthest we need to travel. The half of the side length is also the shortest maximum we need to travel in those directions. The maximum travel distance in all around the centre point must be always between them. We can average them and the shortest travel distance, which is 0, to get an approximate distance. If we average the half diagonal (*hd*), the half of the side (*hs*) and 0, we get a very good approximation which is only 0.86% higher, than the most accurate method:

$$L_a^{averaging,\ 1centre} = \frac{hd + hs + 0}{3} \tag{5}$$

Our first intuition was that we need to average 4 distances: (*hd*,*hs*,0,0), because we need to average first the shortest and the half diagonal, than the shortest and the half side, and then average again to get a result, but due to a random setting, we realized that dividing by 3 gives much better result.

This method works great when we have one centre to locate, but how can we use it when we have more? We find a generalized method when we calculated the average length by dividing area. The full results of this method can be seen in the 3. column in Table II.

4.2. Solution 2: Halving areas

When we examine Fig. 9 a little bit further, we can realize that the average distance needs to be close or exactly on the border of the line, that cuts the entire area in half. The inner half is a circle with the radius of the length of the average distance, and the outer half is the rest of the square. With this, we can calculate the exact distance of one centre's average distance by the following equation:

$$L_a^{area,\ 1centre} = r = \sqrt{\frac{A_c}{\pi}} = \sqrt{\frac{A_s}{2\pi}} \tag{6}$$

This gives a mathematically proven calculation, but it only works if the initial area is a square. If we want to calculate the rest of the problem, we need to examine a possibilities of multiple buildings. If the number of buildings equals to a square number, we can easily cut the area to similar pieces, and use both equations, with the initial area divided by the number of centres. What if we use this strategy to non-square whole numbers. In table II. we present the solution to this method, and the equation for it is:

$$L_a^{area} = r = \sqrt{\frac{A_c}{n_b * \pi}} = \sqrt{\frac{A_s}{2 * n_b * \pi}} \tag{7}$$

We can generalize whit this simplification the method of calculating the average:

$$L_a^{averaging} = \frac{\frac{\sqrt{A_s}}{2} + \sqrt{\frac{A_s}{2}}}{3} \tag{8}$$

With equation (7) and (8) we can calculate the approximate traveling distance with any number of buildings. We can also see in Table II. that there is a close correlation between the two equations, because the deviation is always 0.86%.

We know that these equations has to work for any square numbers, but we can't be sure for any other whole numbers, but there are another less mathematic and more practical method to grant answers.

Table II.

Results of distance calculations and deviations

Number of buildings (nb)	Distance (La) calculated by area	Distance (La) calculated by average	deviation between area and average (%)	Distance (La) calculated by Monte Carlo simulation	deviation between area and simulation (%)
1	39.89	40.24	0.86	38.57	3.32
2	28.21	28.45	0.86	29.62	5.00
3	23.03	23.23	0.86	23.45	1.81
4	19.95	20.12	0.86	19.07	4.40
5	17.84	17.99	0.86	17.39	2.53
6	16.29	16.43	0.86	16.04	1.52
7	15.08	15.21	0.86	14.83	1.65
8	14.10	14.23	0.86	13.81	2.09

4.3. Solution 3: Monte Carlo simulation

With the help of MS-Excel, we can generate a large number of random points, which can be customers, and calculate a straight-line distance between our centres and customers. If we have multiple building, we calculate all distances, and we can choose the closest, with a minimum function. Averaging the minimum distances, we get the average distance of any number of buildings. The only problem is to calculate the optimum point of each centre. The Solver Excel-add-on gave us a great tool for the solution of this problem. With built-in functions, such as the evolution algorithm, it easily determines the exact location of up to 100 centres between a few seconds and half a minute.

With the help of Solver we gathered data between 1 and 8 centres. We did not carry out the investigation further, since the costs did not improve and the difference in the average distance from the different methods is always below 5%. The number of random customer locations was 10,000 and we started the evolution algorithm at least 3 times to get good coordinates for each of our centres. We have included the best of the 3 launches in the 5. column of Table II. In Table III. a solution can be seen for 8 buildings, with their coordinates, average distances, and random locations with distances from these buildings.

At the end of the case study, after we calculated the average distances by the 3 methods, we implemented all of them into the cost calculation by averaging the solutions of the methods. With the input parameters of Table I. and the equations (1) - (4) the total cost can be calculated, which can be seen on Table IV.

Table III.

Example for determining the location of 8 centers using the Monte Carlo method in Excel

#	X coord.	Y coord.	La1	La2	La3	La4	La5	La6	La7	La8	La min
1	30.20	83.77	70.36	30.17	42.14	81.47	44.67	71.84	34.70	54.08	**30.17**
2	90.04	55.50	40.28	69.66	27.60	32.28	33.56	54.98	71.81	21.61	**27.60**
3	86.50	14.28	22.36	77.78	63.55	9.42	44.80	34.15	77.48	61.96	**22.36**
4	11.59	40.50	57.09	17.16	69.78	75.45	46.34	47.86	12.62	80.49	**17.16**
5	39.60	72.77	56.16	26.02	32.20	67.01	30.23	58.73	30.31	44.27	**26.02**
6	96.20	90.74	74.00	83.72	28.62	68.05	57.63	87.12	87.33	19.17	**28.62**
7	8.29	85.99	85.29	33.04	64.11	98.98	61.85	83.19	36.27	76.09	**33.04**
8	91.16	44.10	32.73	71.66	37.46	21.37	34.14	48.23	73.15	32.92	**32.73**
9	85.19	14.73	20.98	76.43	62.81	8.86	43.61	32.83	76.12	61.46	**20.98**
...	...	...	...	...	...	...	...	...	...	...	...

Center	X coord.	Y coord.
1	65.99	23.19
2	20.37	55.24
3	71.63	76.06
4	85.12	23.60
5	57.27	48.24
6	52.37	15.44
7	18.35	51.15
8	83.74	76.17

Average distance	**23.47**

Table IV.

Cost of building different number of centres in the examined area

Number of buildings (nb)	Distance (La) calculated by the average of the 3 methods [km]	Building cost (Cb) [M Eur]	Operation cost (Bo) [M Eur]	Transport cost (Ct) [M Eur]	Total cost [M Eur]
1	39.57	15.00	6.25	59.35	**80.60**
2	28.76	25.00	7.50	43.14	**75.64**
3	23.24	35.00	8.75	34.86	**78.61**
4	19.71	45.00	10.00	29.57	**84.57**
5	17.74	55.00	11.25	26.61	**92.86**
6	16.25	65.00	12.50	24.38	**101.88**
7	15.04	75.00	13.75	22.56	**111.31**
8	14.05	85.00	15.00	21.07	**121.07**

As Fig. 10. shows, the building cost is constantly rising with more centres, the operating costs are also increasing, but a little slowly. Both are semi-linear. Only the transport cost is decreasing, but it cannot keep up with the other two, because it contains a square root function. We can create the most cost effective operation if we build 2 centres in (25,50) and (75,50) or (50,25) and (50,75) coordinate points, where (0,0) (0,100) (100,0) (100,100) is the corner points of the square.

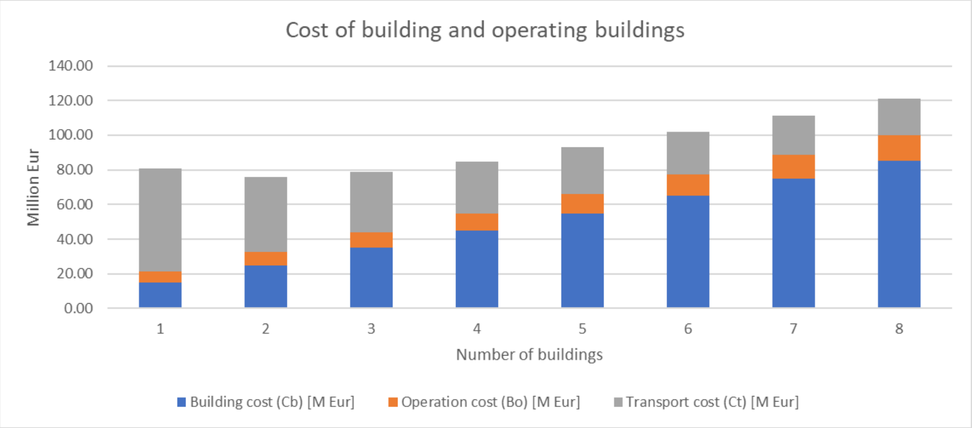

Figure 10. Visualizing the cost of different number of buildings

5. SUMMARY

Facility location plays an important role in the design of supply chain solutions, where the number and layout of facilities must be optimised. The facility location problem can be integrated into the design process of logistics systems. Within the frame of this article the authors show a new methodology, which makes it possible to optimise the location and structure of facilities on a predefined homogeneous plane. The suggested approach integrates the Monte Carlo simulation and an evolutionary Solver algorithm to find the optimal number of facilities, the optimal position of facilities and it is also possible to forecast the average transportation distances in the future supply chain. This research work has important managerial impact, because the facility location problems are generally expensive investment projects, therefore economical decisions can be supported by the results of the abovementioned approach. A potential future research direction is to extend the model for the solution of problems with uncertain parameters.

REFERENCES

[1] Wang, X. (2010). An integrated multi-depot location- inventory-routing problem for logistics distribution system planning of a chain enterprise. 2010 International Conference on Logistics Systems and Intelligent Management, ICLSIM 2010, 3, 5461202, 1427-1431. https://doi.org/10.1109/ICLSIM.2010.5461202

[2] Xu, X., Liu, W., Jiang, M. & Lin, Z. (2022). A multi-cycle and multi-echelon location-routing problem for integrated reverse logistics. *Industrial Management and Data Systems* **122**(10), 2237-2260, https://doi.org/10.1108/IMDS-01-2022-0015

[3] Yang, S., Ning, L., Tong, L. C. & Shang, P. (2022). Integrated electric logistics vehicle recharging station location–routing problem with mixed backhauls and recharging strategies. *Transportation Research Part C: Emerging Technologies* **140**, 103695, https://doi.org/10.1016/j.trc.2022.103695

[4] Agárdi, A., Kovács, L. & Bányai, T. (2019). Two-Echelon Vehicle Routing Problem with Recharge Stations. *Transport and Telecommunication* **20**(4), 305-317, https://doi.org/10.2478/ttj-2019-0025

[5] Veloso, R., Cespedes, J., Caunhye, A. & Alem, D. (2022). Brazilian disaster datasets and real-world instances for optimization and machine learning. *Data in Brief* **42**, 108012, https://doi.org/10.1016/j.dib.2022.108012

[6] Vahdani, B., Veysmoradi, D., Mousavi, S. M. & Amiri, M. (2022). Planning for relief distribution, victim evacuation, redistricting and service sharing under uncertainty. *Socio-Economic Planning Sciences* **80**, 101158, https://doi.org/10.1016/j.seps.2021.101158

[7] Mohammadi, S., Avakh Darestani, S., Vahdani, B. & Alinezhad, A. (2020). A robust neutrosophic fuzzy-based approach to integrate reliable facility location and routing decisions for disaster relief under fairness and aftershocks concerns. *Computers and Industrial Engineering* **148**, 106734, https://doi.org/10.1016/j.cie.2020.106734

[8] Alamatsaz, K., Ahmadi, A. & Mirzapour Al-e-hashem, S. M. J. (2022). A multiobjective model for the green capacitated location-routing problem considering drivers' satisfaction and time window with uncertain demand. *Environmental Science and Pollution Research* **29**(4), 5052-5071, https://doi.org/10.1007/s11356-021-15907-x

[9] Wang, Y., Sun, Y., Guan, X., Fan, J., Xu, M. & Wang, H. (2021). Two-echelon multi-period location routing problem with shared transportation resource. *Knowledge-Based Systems* **226**, 107168, https://doi.org/10.1016/j.knosys.2021.107168

[10] Wang, Y., Sun, Y., Guan, X. & Guo, Y. (2021). Two-Echelon Location-Routing Problem with Time Windows and Transportation Resource Sharing. *Journal of Advanced Transportation* **2021**, 8280686, https://doi.org/10.1155/2021/8280686

[11] Arena, S., Orrù, P. F., Perra, F. & Pilloni, M. T. (2021). Optimization of drugs delivery routes through location routing problem (Lrp): A case study. Inte*rnational Journal of Mechanics and Control* **22**(1), 31-43.

[12] Chen, L., Monteiro, T., Wang, T. & Marcon, E. (2019). Design of shared unit-dose drug distribution network using multi-level particle swarm optimization. *Health Care Management Science* **22**(2), 304-317, https://doi.org/10.1007/s10729-018-9438-6

[13] Zhang, B., Li, H., Li, S. & Peng, J. (2018). Sustainable multi-depot emergency facilities location-routing problem with uncertain information. *Applied Mathematics and Computation* **333**, 506-520, https://doi.org/10.1016/j.amc.2018.03.071

[14] Szabó, A. A., Illés, B. & Bányai, Á. (2020). Industry 4.0 and Logistics 4.0 - Intelligent designs in FMCG logistics. *Advanced Logistic Systems: Theory and Practice* **14**(1), 14-24, https://doi.org/10.32971/als.2020.005

[15] Nagy, G., Illés, B. & Bányai, Á. (2018). Impact of Industry 4.0 on Automotive Supplier Systems. *Conference Proceedings of the 11th International Doctoral Students Workshop on Logistics*, 79-83.

[16] Bányai, Á. (2022). Industry 4.0: challenges and opportunities in packaging logistics. *IOP Conference Series: Materials Science and Engineering* **1235**(1), 012076, https://doi.org/10.1088/1757-899X/1235/1/012076

[17] Bozkaya, B., Yanik, S., Balcisoy, S. (2010). A GIS-based optimization framework for competitive multi-facility location-routing problem. *Networks and Spatial Economics* **10**(3), 297-320, https://doi.org/10.1007/s11067-009-9127-6

[18] Telek, P. & Koštál, P. (2022). Material Handling Equipment Selection Algorithm for Production Workplaces. *Advanced Logistic Systems: Theory and Practice* **16**(2), 37-46, https://doi.org/10.32971/als.2022.011

[19] Telek, P. (2022). Comparison Analysis of Material Handling Solutions of Production Workplaces. *Rezanie i Instrumenty v Tekhnologicheskih Sistemah* **97**(1), 3-20, https://doi.org/10.20998/2078-7405.2022.97.01

[20] Telek, P. (2018). Process-based planning of material handling in manufacturing systems. *IOP Conference Series: Materials Science and Engineering* **448**, 012018, https://doi.org/10.1088/1757-899X/448/1/012018

[21] Schermer, D., Moeini, M. & Wendt, O. (2020). The Traveling Salesman Drone Station Location Problem. *Advances in Intelligent Systems and Computing* **991**, 1129-1138, https://doi.org/10.1007/978-3-030-21803-4_111

[22] Francuz, Á. & Bányai, T. (2022). Branch and bound solution of routing problems for drone-based supply. *Academic Journal of Manufacturing Engineering* **20**(1), 20-26.

[23] Bányai, T. (2022). Impact of the Integration of First-Mile and Last-Mile Drone-Based Operations from Trucks on Energy Efficiency and the Environment. *Drones* **6**(9), 249, https://doi.org/10.3390/drones6090249

[24] Zhang, H., Shi, Y. & Zhang, X. (2019). Optimization for Logistics Center Location in Coastal Tourist Attraction Based on Grey Wolf Optimizer. *Journal of Coastal Research* **94**(sp1), 823-827, https://doi.org/10.2112/SI94-163.1

[25] Jin, Z., Li, Y., Fu, G., Dai, K., Qiu, N., Liu, J., Lin, M. & Qin, Z. (2019). Capacitated Facility Location and Allocation with Uncertain Demand for Tourism Logistics: A Multiobjective Optimisation Approach. *Mathematical Problems in Engineering* **2019**, 4158940, https://doi.org/10.1155/2019/4158940

[26] Peiró, J., Corberán, Á., Laguna, M. & Martí, R. (2018). Models and solution methods for the uncapacitated r-allocation p-hub equitable center problem. *International Transactions in Operational Research* **25**(4), 1241-1267, https://doi.org/10.1111/itor.12441

[27] Hu, Y., Zhang, K., Yang, J. & Wu, Y. (2018). Application of Hierarchical Facility Location-Routing Problem with Optimization of an Underground Logistic System: A Case Study in China. *Mathematical Problems in Engineering* **2018**, 7235048, https://doi.org/10.1155/2018/7235048

[28] Sun, Q., Chien, S., Hu, D.-W. & Ma, B.-S. (2018). Optimizing the Location-Inventory-Routing Problem for Perishable Products Considering Food Waste and Fuel Consumption. CICTP 2018: Intelligence, *Connectivity, and Mobility - Proceedings of the 18th COTA International Conference of Transportation Professionals*, 482-491, https://doi.org/10.1061/9780784481523.048

[29] Xie, W. & Ouyang, Y. (2015). Optimal layout of transshipment facility locations on an infinite homogeneous plane. *Transportation Research Part B: Methodological* **75**, 74-88, https://doi.org/10.1016/j.trb.2015.02.001

[30] Michael W. K. Y., Saad, D. & Yeung, C. H. (2016). Distributed optimization in transportation and logistics networks. *IEICE Transactions on Communications* **E99B**(11), 2237-2246, https://doi.org/10.1587/transcom.2016NEI0003

[31] Dong, Z. & Turnquist, M. A. (2015). Combining service frequency and vehicle routing for managing supplier shipments. *Transportation Research Part E: Logistics and Transportation Review* **79**, 231-243, https://doi.org/10.1016/j.tre.2015.05.002

[32] Ting, C.-J. & Chen, C.-H. (2013). A multiple ant colony optimization algorithm for the capacitated location routing problem. *International Journal of Production Economics* **141**(1), 34-44, https://doi.org/10.1016/j.ijpe.2012.06.011

[33] Carnes, T. & Shmoys, D. B. (2011). Primal-dual schema and Lagrangian relaxation for the k-location-routing problem. *Lecture Notes in Computer Science* **6845**, 99-110, https://doi.org/10.1007/978-3-642-22935-0_9

[34] Manzini, R., Bindi, F., Bortolini, M. & Giovannini, A. (2011). LD Logoptimizer: A software tool for the strategic and operational design of a logistic distribution system. *Supply-Chain Management: Theories, Activities/Functions and Problems* **2011**, 255-274.

[35] Mar-Ortiz, J., Adenso-Diaz, B. & González-Velarde, J. L. (2011). Design of a recovery network for WEEE collection: The case of Galicia, Spain. *Journal of the Operational Research Society* **62**(8), 1471-1484, https://doi.org/10.1057/jors.2010.114

[36] Zeng, M., Cui, Z. & Wu, X. (2009). Research on location-routing problem of relief system based on emergency logistics. *IE and EM 2009 - Proceedings 2009 IEEE 16th International Conference on Industrial Engineering and Engineering Management*, **5344599**, 228-232, https://doi.org/10.1109/ICIEEM.2009.5344599

[37] Zhao, J. & Ke, G. Y. (2017). Incorporating inventory risks in location-routing models for explosive waste management. *International Journal of Production Economics* **193**, 123-136, https://doi.org/10.1016/j.ijpe.2017.07.001

[38] Bozorgi-Amiri, A. & Khorsi, M. (2016). A dynamic multi-objective location–routing model for relief logistic planning under uncertainty on demand, travel time, and cost parameters. International *Journal of Advanced Manufacturing Technology* **85**(5-8), 1633-1648, https://doi.org/10.1007/s00170-015-7923-3

[39] Gündüz, H. I., Hempsch, C. K. & Sebastian, H.-J. (2015). Recent Advances in Strategic and Tactical Planning of Distribution Subnetworks for Letter Mail. *Lecture Notes in Logistics* **2015**, 105-128, https://doi.org/10.1007/978-3-319-12856-6_5

[40] Singh, T. P., Neagu, N., Quattrone, M. & Briet, P. (2015). Network design for cylinder gas distribution. *Journal of Industrial Engineering and Management* **8**(1), 85-109, https://doi.org/10.3926/jiem.1140

[41] Do Amaral, M., Almeida, M. S. & Morabito, R. (2012). A model for flow allocation and location of intermodal terminals for the Brazilian soybean exports. *Gestao e Producao* **19**(4), 717-732, https://doi.org/10.1590/s0104-530x2012000400005

[42] Ghanmi, A. (2011). Canadian forces global reach support hubs: Facility location and aircraft routing models. *Journal of the Operational Research Society* **62**(4), 638-650, https://doi.org/10.1057/jors.2010.22

[43] Gunnarsson, H., Rönnqvist, M. & Carlsson, D. (2006). A combined terminal location and ship routing problem. *Journal of the Operational Research Society* **57**(8), 928-938, https://doi.org/10.1057/palgrave.jors.2602057

[44] Chan, Y. & Baker, S. F. (2005). The multiple depot, multiple traveling salesmen facility-location problem: Vehicle range, service frequency, and heuristic implementations. *Mathematical and Computer Modelling* **41**(8-9), 1035-1053, https://doi.org/10.1016/j.mcm.2003.08.011