

Strategic Approach to Implementation and Integration of Routing-Based Tasks in Warehouse Management Information Systems

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Abstract: One of the frequently occurring tasks during the development of warehouse management systems is the implementation of routing algorithms of some kind. Whether it is for routing workers during order picking, delivery vehicles or company representatives, this task has proven to be challenging in the technical as well as the social sense. In other words, the task is heavily dependent on various general and company-specific constraints and it directly dictates the way employees should do their job. This paper describes a strategic approach to the development and gradual integration of such algorithms which makes sure that all constraints are satisfied and, more importantly, ensures that route suggestions are viewed by the employees as a helpful tool rather than a threat to their job. In the first part of this paper, the approach is described and evaluated on a warehouse representative routing problem through a real-world case study in a medium-to-large warehouse. In the second part, the same approach is adapted to a delivery vehicle routing problem for a smaller retailer company. In both cases, routing efficiency almost doubled in comparison to previous approaches used by the companies. The most important factors of the implementation and integration stages as well as the impact of the changes on employee satisfaction are aggregated, analysed in detail, and discussed throughout different stages of development.

Key words: Clustering, routing algorithms, travelling salesman problem, warehouse management system.

1. Introduction

The development of a warehouse management system (*abbr.* WMS) typically consists out of multiple stages since there are a lot of fundamentally different business processes that need to be modelled. Various different classifications exist, but according to [1] the most basic processes in a warehouse are: receiving, storing, put-away, picking/retrieving, and shipping. Each of these processes is heavily dependent on a multitude of factors, like the rules of pre-existing business models or the layout of the warehouse which makes the implementation of these systems challenging. Furthermore, the modelling of seemingly-easy tasks frequently requires utilization of advanced algorithms of some kind. Because of that, smart warehouse concepts based on artificial intelligence and machine learning [2] are a frequent occurrence in recent times. On the other hand, some companies choose to buy and adapt pre-developed enterprise solutions in the workflow to avoid the development process altogether. This approach is easier from a planning standpoint,

but it can be rather difficult and expensive, especially for smaller companies because such solutions are difficult to adapt to company-specific constraints and basic, scaled-down needs of such companies.

An appropriate example of such complex processes are the ones which require utilization of routing algorithms, like the routing of workers inside the warehouse or the routing of delivery vehicles during shipping. Even though these processes are conceptually very simple, they consist out of multiple non-trivial tasks which need to be well-synchronized to achieve acceptable results. Besides just the complexity of the technical implementation, there are also a lot of uncontrollable factors (e.g., warehouse layout limitations or traffic congestions) which can affect the performance. This is especially the case during shipping. Generation of delivery routes, choosing available vehicles and determining their respective loads, and real-time handling of setbacks represents a challenge even for advanced algorithms. However, finding efficient solutions for these tasks can lower the resource costs and bring significant profit to the company.

Besides cutting costs, another benefit is establishing and maintaining strong relationships with the customers. If the deliveries are exact and done on time, the chance that customers remain loyal increases significantly. Given that this depends on the successful execution of shipping routes, cooperation from the employees is vital. However, the majority of changes, especially if they disrupt the usual workflow, is naturally resisted among company employees. This is most notable for companies that did not make use of similar solutions before. Therefore, the implementation and integration phases of routing-based processes in WMS's should be approached carefully and introduced gradually in order to achieve optimal results.

As with any larger information system, the analysis, design and implementation of a WMS needs to be done based on detailed planning. Furthermore, WMS's are special in a sense that they are like an interconnected pipeline of complex subsystems that heavily depend on each other and the input precision of employees. Therefore, it is important to have a strategic approach to the design and development of individual subsystems as well as their integration, all while keeping the plethora of constraints in mind.

This paper is organized as follows: In the Introduction section, the importance of strategic analysis and design of routing-based processes in WMS's was highlighted. In the Related Work section, relevant literature about WMS development and state-of-the-art routing algorithms is analysed and discussed. In the Methods and Experiments section, the underlying case studies are established, the development of the novel approach is described and appropriate experiments are designed. The analysis of the results and the discussion of technical and social implications is stated in the Results and Discussion section. In the end, the paper concludes with appropriate remarks and directions for future research.

2. Related Work

Due to the size and complexity of the processes being modelled, during the design of a WMS various different factors need to be taken into consideration. Those factors are either internal or external depending on whether the process is taking place inside or outside the warehouse. One of the most important internal factors is the overall layout design of the warehouse, which, according to [1], can have over 60% effect on the total travel distance of warehouse employees. The most common layouts are the result of following the basic design rules [3]: 'picking aisles must be straight and parallel to one another' and 'if present, cross-aisles must be straight, and they must meet picking aisles at right angles'. However, in [4] the authors prove that some unconventional layouts, like the Flying-V and Fishbone layouts, have more advantages than traditional layouts when it comes to the travel distance reduction. The authors achieve a reduction of 20% and 15% of the traveled distance in single-command and dual-command operations respectively.

Besides the layout, factors like warehouse size, the number of employees and the level of automation present in the warehouse can also have a major impact on the overall design of the WMS. On the other hand, one of the most important external factors is the geographical position of the warehouse, but traffic

connections or available vehicles are also things that need to be taken into consideration. Some of these factors have greater impact on the efficiency than others, because they are hard or even impossible to change, unless all of the infrastructure is constructed in coordination with the pre-designed WMS [5].

As mentioned previously, real-world applications of routing algorithms are still an area of intensive research given their high complexity. What makes this area so difficult to optimize are the constraints and unexpected delays that arise in such dynamic environments. Today, such problems are usually defined through the Vehicle Routing Problem (*abbr.* VRP) or, in the special case, a Travelling Salesman Problem (*abbr.* TSP) depending on specific constraints and the subjects being routed. These are well-known NP-hard problems in the field of combinatorial optimization and many researches focus on finding a solution [6] or generally applicable relaxations. The main objective in these problems is to minimize the overall travelled distance of the routed subject. Various algorithms are used to achieve that goal, but in the basic case, where the number of locations is relatively small, frequently used algorithms are based on 2-opt [7] and 3-opt [8] approaches or the Ant Colony Optimization [9] (*abbr.* ACO). While these approaches are efficient, in cases where the number of locations is much larger, other solutions may provide faster and more exact solutions.

In cases where the number of locations that need to be visited is much larger, two opposing optimization goals become apparent: overall computation time and quality of the generated routes. Especially when it comes to solving TSPs with a large number of locations, the main question is how to handle the trade-off between these two objectives. In order to generate higher quality routes, algorithms need to run longer and vice versa. In some cases it is challenging to find one possible solution, let alone the optimal one. Even with computational power available today, an efficient solution for this problem still does not exist.

This problem is showcased in [10] where a Self-Organizing Map (*abbr.* SOM) approach is applied for solving the TSP. Adapting SOM to solve the problem did not bring any improvements, but the combination with a local search algorithm has shown improvements in terms of processing time. However, the generated routes were not the optimal solution compared to results from other researches. Accordingly, while advanced algorithms can be adapted to solve these problems, the inherent complex nature of the problem makes it hard to achieve quality results in a reasonable amount of processing time.

This complex nature of these problems is indicated in [11] and the authors propose a new algorithm based on Simulated Annealing (*abbr.* SA) and Gene Expression Programming (*abbr.* GEP) to find the optimal solution. Reported results show that the approach outperforms other heuristic algorithms in execution time and quality. In [12] the authors apply the Genetic Algorithm (*abbr.* GA) for solving the VRP by relaxing the problem to a TSP. The conclusion was that the time needed to solve the VRP can be significantly reduced if the problem is coded as a TSP, because the obtained results were very close to the optimum. Research [13] reports the usage of GA for solving the TSP and uses a collaboration model as an alternative strategy. However, despite decent results, experiments are carried out on simulated data and the authors indicate that it would be beneficial to carry out case studies with real data in order to discover their full potential.

No matter how much improvement routing algorithms show in simulated environments, during integration and test runs their real efficiency is still decided on a case-by-case basis. Therefore, analyzing related researches which describe the approaches through real-world case studies, report encountered pitfalls, and offer valuable solutions is very important during the WMS development process. Such content is described in [14] where the authors apply the TSP in terms of shipping companies and Black Sea ports by using graph theory based algorithms to generate the optimal routes. In [15] the goal was to find the cheapest configuration of routing the electrical supply cables which connect the turbines to the collection center. The TSP and multiple TSP (*abbr.* mTSP) models were used to find the optimal route and this approach has shown promising results. In [16] the authors applied several TSP algorithms to generate the shortest routes for drones to visit the maximum amount of their tasks before returning to port to recharge.

All of the mentioned researches represent valuable guidelines and sources of ideas when routing-based processes are being modelled. However, no matter what algorithm is being utilized, it is almost certain that the underlying (general or company-specific) constraints will throttle the full potential of the implemented solution. Because of this, it is important to have a strategic, gradual approach for the implementation and integration of any routing-based process in the WMS.

3. Methods and Experiments

In order to appropriately describe the development implications of this approach as a part of a larger WMS project, it is necessary to define a clear starting point and describe the starting conditions. This is done through the analysis of a real-world case study example, which was developed based on a long-term project for a retail logistics company located in Bosnia and Herzegovina. The WMS was initially developed and tested in a medium-to-large warehouse located in the capital and then transferred to other distribution centers across the country. Afterwards, as a new project proposal to the company, the approach was adapted and tested out on a delivery vehicle routing problem for a smaller retail company. This application of the approach was modelled as a smaller case study in order to showcase the adaptability of the solution.

3.1. Case Study Settings

The main objective of both of these companies was to improve the route quality through the development of an efficient and applicable approach, despite a lot of existing constraints. In order to overcome constraints, an in-depth analysis of the pre-existing workflow needed to be done.

3.1.1. Warehouse representative routing

Before the start of the system development life cycle, only a rudimentary form of automation was present in the warehouse. The majority of the conclusions and suggestions presented throughout the paper are based on observations made during the integration of the developed components.

During the initial phase of the development, only the basic functionalities were introduced such as tracking of the entry and movement of wares and the inventory processes. However, these operations required a lot of important preparation work to be done, like marking of the pallet places in the form of three-dimensional space, adequate labeling of those pallet places and supplying handheld barcode scanners with fitting applications. Reliable implementation of the core warehouse processes, as shown in Fig. 1, is a critical step since all the future components and sub-systems rely on them. Moreover, fast implementation of the basic tasks enables collecting valuable information before the system is operational. These initial improvements immediately resonated well with the employees since it made their everyday routines easier to handle. After this was done, other functionalities like customer returns registration and repositioning of returning wares back into the picking zone were implemented. Even though these operations were not critical, a fitting solution resulted in the minimization of necessary space and human resources. This proves that no operation should be overlooked during analysis since automation could bring significant benefits.

After the initial version has stabilized and the employees have grown used to using it, the next step was the implementation of more complex components. The first such task was the determination of the optimal path for the collection of items during order picking. This developed solution [17] included attributes such as the expiry date, weight and the priority of the items. Through a detailed analysis of the sales data collected over this period when the initial WMS version was operational, associative rules were established among articles with firm correlation links. The opportunity for further improvement was to place the articles frequently ordered together close to each other in the warehouse racks in order to make the gathering process faster and more efficient [18] overall. This was done immediately after registering the goods into the warehouse, where the optimal empty rack position for storing was indicated.

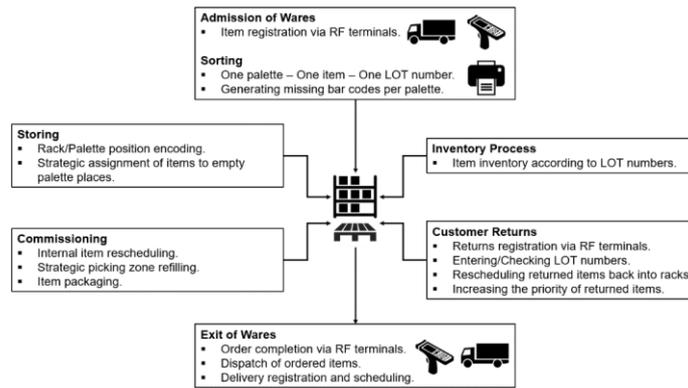


Fig. 1. The core processes that need to be included during the implementation of the WMS.

The efficiency of the warehouse workers further increased with these upgrades, but the satisfaction with the changes was not necessarily high. This was a good indicator that WMS components that directly alter the way tasks are executed are more likely to cause dissatisfaction among the company employees.

After the changes in the internal organization of the warehouse have shown that there is significant room for improvement, the next step was assessing opportunities for similar optimizations in processes happening outside the warehouse. After the analysis, two processes were identified as room for potential improvement: routing of delivery vehicles and representative routing. Delivery is the process where the ordered goods are being delivered to the final customers and during representative visits employees meet customers, take their orders, talk about promotions and briefly discuss business-related topics. Since the tasks are fairly similar and the routing of delivery vehicles requires a lot more planning and cooperation from all levels of management, it was decided to start with the representative routing task. The delivery vehicle routing task of this scale is still in development and a lot of observations and conclusions made during the implementation of representative routing task are being utilized in order to improve efficiency.

3.1.2. Delivery vehicle routing

Since this case study is a project proposal where the implemented approach is being adapted and tested on data from another company, pre-existing levels of infrastructure automation in the new environment are unknown. The majority of the made conclusions is based on observations during adaptation and testing.

Based on the successful implementation in the case of representative routing, companies were starting to gain interest in the developed approach. However, most of the problems were conceptually different than the original and this was a good opportunity to test out the adaptation flexibility of the approach. Such an opportunity came in the form of a delivery vehicle routing problem from a central warehouse to branch stores at various locations across Bosnia and Herzegovina for one of the largest clothing retail chains in the country. The main objective of the delivery vehicle routing problem is to generate optimal loads and routes for a fleet of available vehicles, as illustrated in Fig. 2, for a given period of time (e.g., daily, weekly, monthly).

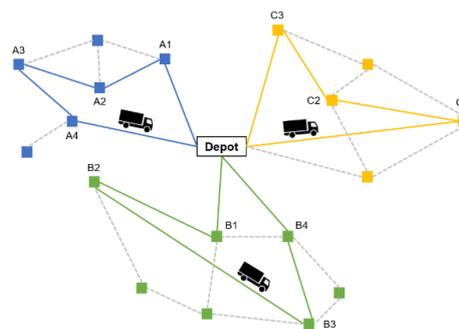


Fig. 2. Illustration of the delivery vehicle routing problem.

Delivery routes in such chain stores in underdeveloped countries are mostly based on the experience of managers. In this case, route generation was done through three steps: identify the centers of cities, assign vehicles to those centers, and assign customers located around those centers to same delivery routes. This approach is somewhat similar to clustering, but it is hard to expect that a human is able to generate clusters that are optimal, or even sub-optimal. Such plans are made on a daily basis based on previous orders which is not efficient. However, generating delivery routes on a weekly or monthly basis implies a significant increase in the number of possible combinations which is impossible even for highly experienced managers.

The basic premise of this problem is more-or-less the same as in the case of representative routing. However, the major difference is the calculation of vehicle loads and the calculation of the unloading time at individual locations, which needs to be additionally calculated. The presence of unloading implies that the routes for the delivery vehicle routing problem will be much shorter.

3.2. Problem Definition

Customers of a specific distribution warehouse are divided into regions based on their geographical location and representative visits are scheduled on a weekly basis, e.g. once a week, once every two weeks etc. There are also constraints that need to be respected. In this specific case, the constraints that could not be avoided in order to create more efficient routes were as follows:

1. *Brand-specific representatives* – Some brands may require specifically assigned employees to make the visits instead of regular warehouse employees.
2. *Preferred day of the visit* – Some customers have exclusively assigned days for accepting visits.

These constraints directly influence either the set of locations or the representative that needs to visit those locations. Fortunately, this can be solved by generation of disjunct sets of locations that can be later assigned to a fitting set of employees prior to the actual route generation and optimization process. Since these constraints need to be respected, this approach splits the main set into smaller parts, which reduces the overall complexity of the problem. However, route optimization still remains the main challenge. The route of a single representative can be formulated as follows:

$$\begin{aligned}
 & est_{tt}(l_0, l_1) + est_{ct}(l_1) + \\
 & + est_{tt}(l_1, l_2) + est_{ct}(l_2) + \\
 & \quad + \dots + \\
 & + est_{tt}(l_{n-1}, l_n) \leq t_{wh}
 \end{aligned} \tag{1}$$

where l represents the location of the representative (including the starting l_0 and the end l_n positions), est_{tt} is the estimated traveling time between two locations, est_{ct} the estimated time spent with the customer and t_{wh} the working hours of the representative. In the case of the warehouse representative routing problem, estimation of traveling time is directly obtained from a routing service, while the estimation of the average time spent during a visit is calculated as the average time from the historical data about previous visits. In the case of the delivery vehicle routing traveling time is also fetched from a service, but the unloading time needs to be calculated more carefully. Unloading time for a single vehicle is calculated as follows:

1. Fetch the average number of boxes $avg(n_{box})$ loaded on this vehicle type for a single day. (e.g., 15 pcs.)
2. Calculate average unloading $avg(t_{ul})$ time for the specific vehicle. (e.g., 30 mins.)
3. Depending on if the number of actual boxes for a vehicle is smaller or larger than the average, the unloading time is calculated like:

$$est_{ct}(l_n) = avg(t_{ul}) + (n_{box} - avg(n_{box})) \frac{avg(t_{ul})}{avg(n_{box})} \tag{2}$$

Since estimates like (2) do not guarantee exact results and there is always a possibility of unpredictable circumstances (e.g., traffic congestions), additional time can be lost. Similarly, those values can also be roughly estimated from the historical data. For this reason, an additional parameter t_{loss} is added to compensate for unplanned time losses. If this is taken into consideration, the formulation becomes:

$$\sum_{i=0}^{n-1} (est_{tt}(l_i, l_{i+1}) + est_{ct}(l_{i+1})) + t_{loss} \leq t_{wh} \tag{3}$$

$$\max_n \left(\sum_{i=0}^{n-1} (est_{tt}(l_i, l_{i+1}) + est_{ct}(l_{i+1})) \right) \leq t_{wh} - t_{loss} \tag{4}$$

According to (3), the only thing that can be directly influenced are the route points and the visiting order. In order to obtain the optimal routes, the number of visited locations needs to be as high as possible and the travelling time between them as short as possible. The overall travelling time together with the estimated time losses needs to be shorter than the defined work hours of the representative. According to these statements, route generation for a representative is formulated as a constrained maximization problem as stated in (4). In order to cover all locations, this problem needs to be solved for multiple representatives.

3.3. Basic TSP Solution

The basic problem solution consists of three main steps as depicted in Fig. 3. In this specific case, the customer list is predefined but not static since the agreements with customers can be suspended and re-opened relatively quickly. Therefore, the visiting frequency is carefully determined based on historical data and the preferences and the current status of the customer in question.

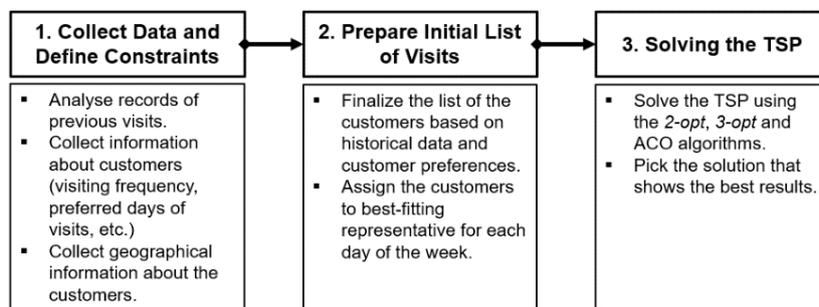


Fig. 3. Main steps of the solution for the basic TSP.

In the first step, all of the necessary information about the customers is collected. The records of previous visits are analyzed and the last successfully executed order for each customer is confirmed. For each of these customers, the visiting frequency and geographical location is collected. With this step, the construction of the list of visits is finalized. Next, all non-relaxable constraints are defined. The constraint with the highest priority is the visiting frequency which affects how the visiting list will be constructed. However, customers can have pre-defined visiting days or preferred retailers, which needs to be considered.

During the second step, the visiting schedule for each customer is determined based on the previously defined constraints. The list is manually revised and sometimes adjusted to additional constraints if needed. After completing this step, the customers are assigned to the best-fitting representatives for each day of the week, and the necessary inputs for the TSP solvers is prepared.

Finally, in the last step, the TSP is solved by the mentioned 2-opt, 3-opt and ACO algorithms. Given that the set of visiting locations is split due to constraints and therefore not significantly large, these algorithms provide quality results. Routes from the generated solutions are compared and the best solution is selected. It is worth noting that TSP solvers run for each customer and for each day separately, which is inefficient.

3.4. Improving the TSP Solution

After the problem has been defined, the question is whether further improvements are possible. One idea is to further split the set of locations into smaller sets based on their geographical proximity and traffic connection. Finding the underlying spatial relationships of geographic locations is an appropriate task for clustering algorithms [19] with proper modifications. As depicted in Fig. 4, the set of location is initially grouped into “macro-clusters” by utilizing the DBSCAN [20] clustering algorithm. All of the outliers produced by the algorithm are being assigned to the nearest macro-cluster. This is done in order to create complete regions which will later alleviate the generation of balanced routes. After the macro-clusters have been created, the next step is to generate the routes which is done with k-means clustering. After the initial routes have been generated for a single macro-cluster, they are checked whether the working hours constraint is satisfied. If this is the case for all routes, the process terminates. If some routes are still unmanageable by a single representative, the number of clusters is increased and the clustering process is repeated. However, if further increase of the number of clusters does not improve overall route quality, the process needs to be terminated. Some clusters are naturally too dense and cannot be broken down any further so they need to be divided into manageable routes which is not complicated given their proximity.

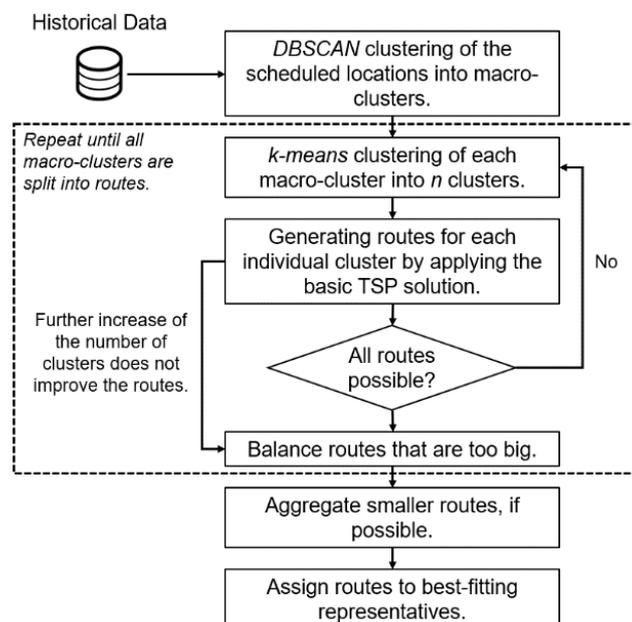


Fig. 4. Clustering-based route generation approach.

After this iterative process is concluded, the final step is to revisit all the generated routes and check whether some of them can be aggregated. After this step, the routes can be assigned to any representative which leaves room for satisfying additional constraints that may arise. This process is visually depicted in Fig. 5. It is interesting to note that in step 5, the two routes which belonged to two different macro-clusters can still be aggregated because that results in a more efficient route.

Conceptually, this approach should also bring improvements in terms of the balance and efficiency of the generated routes as well as lower calculation time. The 2-opt, 3-opt and ACO algorithms for solving the TSP perform well in environments where the set of locations is not that big and there are not that many limiting factors for the travelling subjects. However, in real-world applications, it is always preferable to leave some room for maneuvering in case such unexpected situations occur. On the other hand, clustering of locations into macro-clusters significantly alleviates the solving of the TSP since it reduces the number of locations that need to be analysed each iteration. This divides the main TSP into smaller subproblems which are much easier to handle and solve with the aforementioned algorithms.

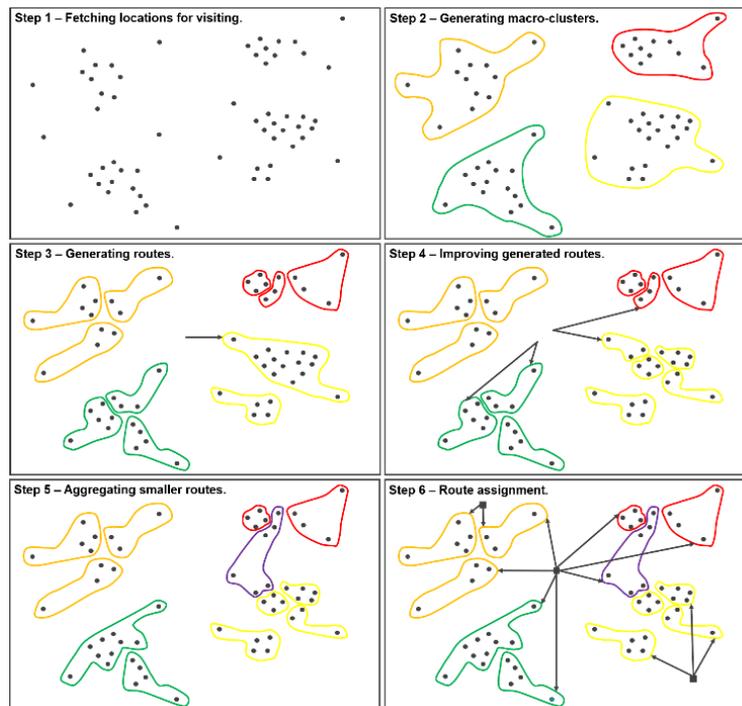


Fig. 5. Visual representation of the clustering-based route generation approach.

3.5. Data and Experiment Design

The data used for benchmarking of the developed approach are real-world data from the companies that were described in the case studies. In case of the representative routing, data were collected during the time the initial version of the WMS was operational. This data contains all of the necessary information about the customers, their respective locations, representatives, sales numbers and previous visits registered by each representative. In the case of delivery vehicle routing, previous routing data were made available by the company to assess the possibilities of the developed approach. In either case, having access to this kind of data are really valuable since it makes trend analysis and the detection of underlying patterns possible, thus enabling the development of more efficient solutions for the WMS components developed in the future. After detailed analysis of the case studies, three key factors were chosen as the basis for the design of the experiments: efficiency, integration in a pre-existing work environment, and the overall adaptability.

The testing of the efficiency needed to be analysed in the short term as well as in the long term in order to get a clear picture whether any improvement has been made. Two sets of experiments were designed for testing the efficiency on a daily and on a weekly basis in terms of the amount of spent resources and the quality of the generated routes. The comparison was made between the *ad hoc* approach used before the new approach, basic TSP solver algorithms and the clustering-based improvement of the basic TSP solution.

Experiments for measuring the integration quality and the social implications of the developed approach amongst warehouse employees were much harder to execute. Given that the second case study is more similar to a project proposal, this experiment is limited only to the representative routing case. Informal interviews were conducted during each stage of the integration process, with employees from operational as well as management positions. Additionally, behaviours of all employees were observed during the implementation of the changes. In order to test the overall adaptability of the developed approach, it was applied to a conceptually different problem. Some additional calculations (e.g., the unloading time) were done, but the core concept remained the same.

The sets of locations and routes used throughout these experiments will be made available for use by other researchers. For further information about the data, contact the corresponding author.

4. Results and Discussion

The experiments in this section were primarily designed to test the improvements and adaptability of the new approaches as well as to study employee reaction to significant changes in their workflow. The final results led to interesting conclusions which can be utilized during the development of any similar system.

4.1. Representative Routing Results Analysis

In order to test whether the new approaches to representative routing brought significant improvements, the results needed to be compared with the previously used ad hoc approach to routing. This was done by comparing the results of all three approaches on the same set of locations, in the same time period of three weeks spanning from randomly selected dates between 05.08.2019 to 26.08.2019. The results in terms of the minimum number of representatives needed are presented in Table 1.

Table 1. Minimum Number of Employed Representatives

Time Period	<i>ad hoc</i>	Basic TSP	Clustering TSP
Daily	66	35	30
Weekly	88	43	37
Total	92	44	37

Judging from these results, both of the newly introduced approaches significantly outperform the previous approach by reducing the utmost minimum amount of needed representatives almost in half. Even though this does not reflect the real number of needed human resources, it indicates that there is room for major improvement. As far as the number of generated routes goes, the numbers are presented in Table II.

Table 2. Average Number of Generated Representative Routes

Time Period	<i>ad hoc</i>	Basic TSP	Clustering TSP
Daily	65.8	41.3	34.7
Weekly	236	121.1	87
Total	502	243	174

Similar to the previous case, the number of generated routes is again almost cut in half, which indicates the increase in overall route quality. Furthermore, the advantage of using clustering is more visible since the average number of generated routes drops notably in comparison to the number of routes generated by the basic TSP approach. Additional route quality indicators were analysed and presented in Table III.

Table 3. Additional Quality Indicators of Generated Representative Routes

	<i>ad hoc</i>	Basic TSP	Clustering TSP
Most Frequent Route Length	6	18	19
Longest Route	48	38	20
Average Route Length	8.77	12.63	14.93
Average Time Duration (h)	4.13	6.04	6.94

To further test the developed approaches, the following quality indicators were also analyzed: most frequent route length, longest route, average route length, and average route duration. The results in this table confirm the superiority of the new approaches which is highlighted the most in the average route length and duration. Taking into consideration that the average route length is 6.94 hours, which is very close to the usual working time of 8 hours, it is clear that the quality of the routes is increasing while the set constraints are being respected. To have a complete picture of the route quality trends, it is useful to visually represent some examples. In Fig. 6, the daily route quality for a randomly selected date (14.08.2019)

is compared for the same set of locations taken from the database.

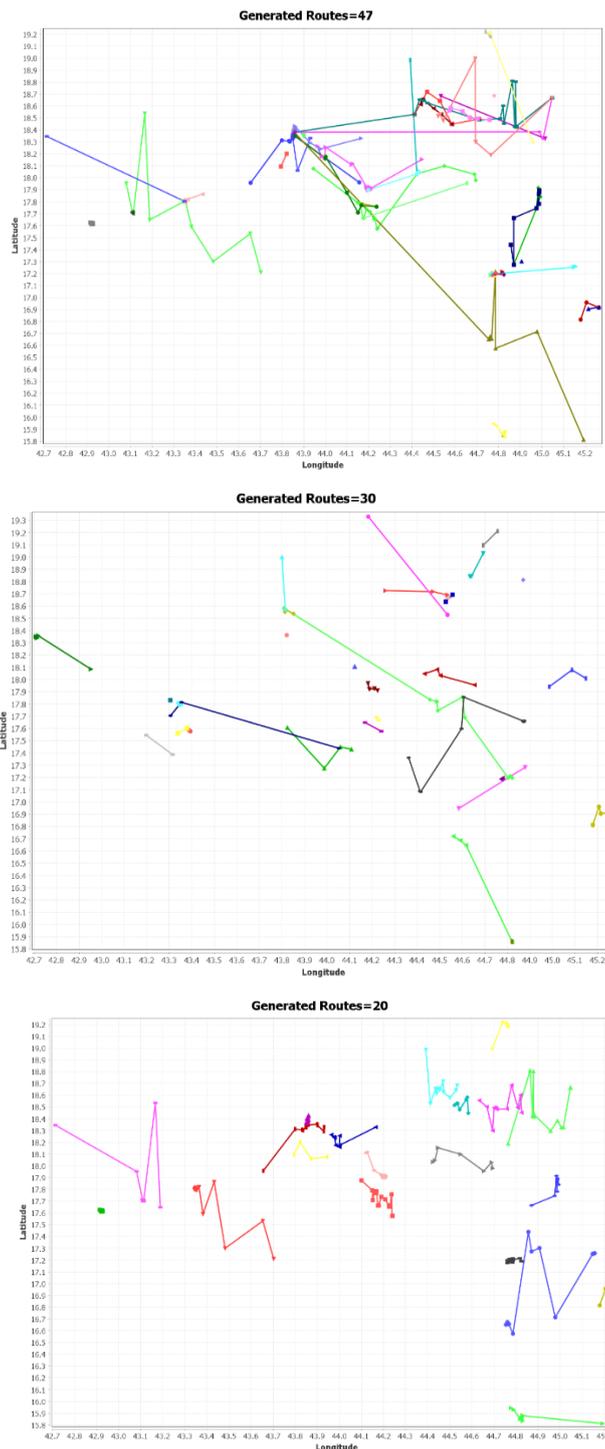


Fig. 6. Simple visual representation of the generated daily routes for the representative routing problem from the a) *ad hoc* approach, b) basic TSP approach, and c) clustering-based TSP approach.

Even though visual inspection is not necessarily an exact measure, it is clearly visible from the examples that the routes generated by the new approaches represent more concise and clearly defined routes. Based on all of these indicators, it can be concluded that the previously used *ad hoc* approach was outperformed by a significant margin in comparison to the new approaches. The overall efficiency of the routes, in terms of quality and required human resources, almost doubled. Although not by that of large margin, using clustering to refine the TSP approach brought additional improvements in terms of route quality in

comparison to its basic counterpart. However, it is important to note that the clustering-based approach was executed significantly faster given that the TSP solvers were used on multiple smaller location sets.

4.2. Delivery Vehicle Routing Results Analysis

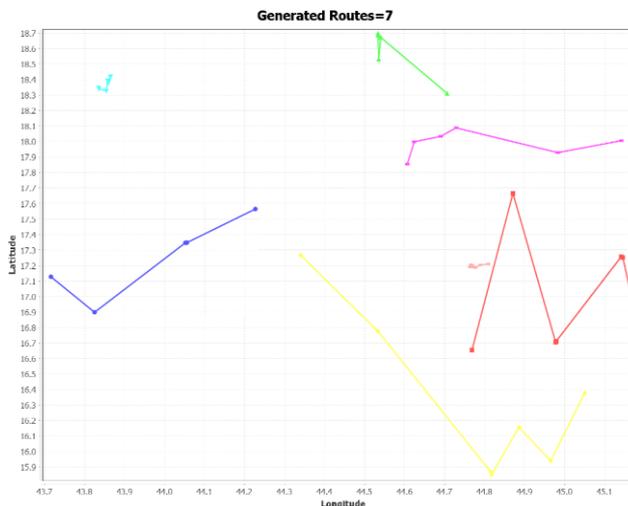
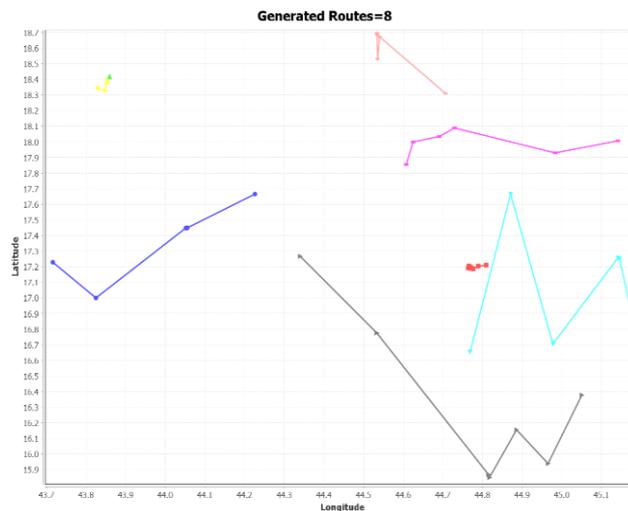
Since the two problems are conceptually very similar, the same metrics as before can be used to assess whether any improvement has been made. The data that was made available was for the month of July, 2019. Therefore, the same comparison was made on the same set of locations, in the time period spanning from 01.07.2019 to 31.07.2019. The results are presented in Table 4.

Table 4. Minimum Number of Employed Drivers and Average Number of Generated Delivery Vehicle Routes

Time Period	<i>ad hoc</i>		Basic TSP		Clustering TSP	
	Emp.	Rts.	Emp.	Rts.	Emp.	Rts.
Daily	9	8.14	8	7.56	7	6.73
Weekly	15	42.5	11	40.5	10	37.5

Table 5. Additional Quality Indicators of Generated Delivery Routes

	<i>ad hoc</i>	Basic TSP	Clustering TSP
Most Frequent Route Length	6	7	9
Longest Route	13	15	21
Average Route Length	6.23	6.57	12.01
Average Time Duration (h)	5.02	5.46	6.68



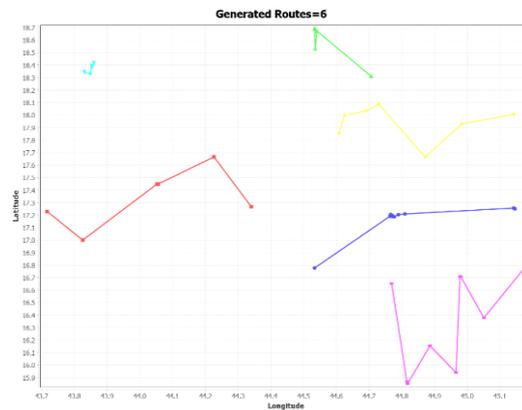
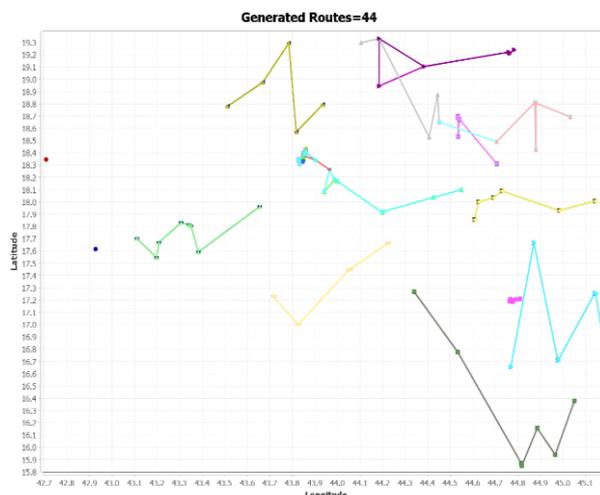


Fig. 7. Simple visual representation of the generated daily routes for the delivery vehicle routing problem from the a) *ad hoc* approach, b) basic TSP approach, and c) clustering-based TSP approach.

Although the numbers are significantly lower because this retail company is much smaller in comparison to the previous warehouse, the results are very similar. The minimal number of representatives as well as the daily and weekly averages of generated routes significantly drop when the new approaches are applied. To further test the adaptability of the approaches, additional route quality indicators were analysed and presented in Table 5.

In this case, the average route length is 6.68 hours for the clustering-based TSP approach, but other approaches also have acceptable route durations. This indicates that the old routes were made based on some advanced planning strategies. To complete the comparison, it is useful to visually represent some examples. In Fig. 7 and Fig. 8, the daily and weekly route quality for a randomly selected date (25.07.2019) and a randomly selected week (01.07.2019 – 07.07.2019) respectively, are compared for the same set of locations taken from the data that was made available. As mentioned in the previous section, even if a visual inspection is not necessarily an exact measure, it can show useful trends. In this case, the difference between the *ad hoc* and basic TSP approaches is not that large, which somewhat confirms the assumption that the old routes were not just heuristically created and gradually improved, but rather are a result of careful planning. However, the clustering-based TSP approach significantly outperforms both of them as it cuts the number of weekly routes in half. There is also a slight improvement in the quality of daily routes, however, this number of locations is too small of a sample to draw any significant conclusions. Finally, given that the number of locations in this case study was significantly lower, both of the approaches were executed in approximately the same amount of time.



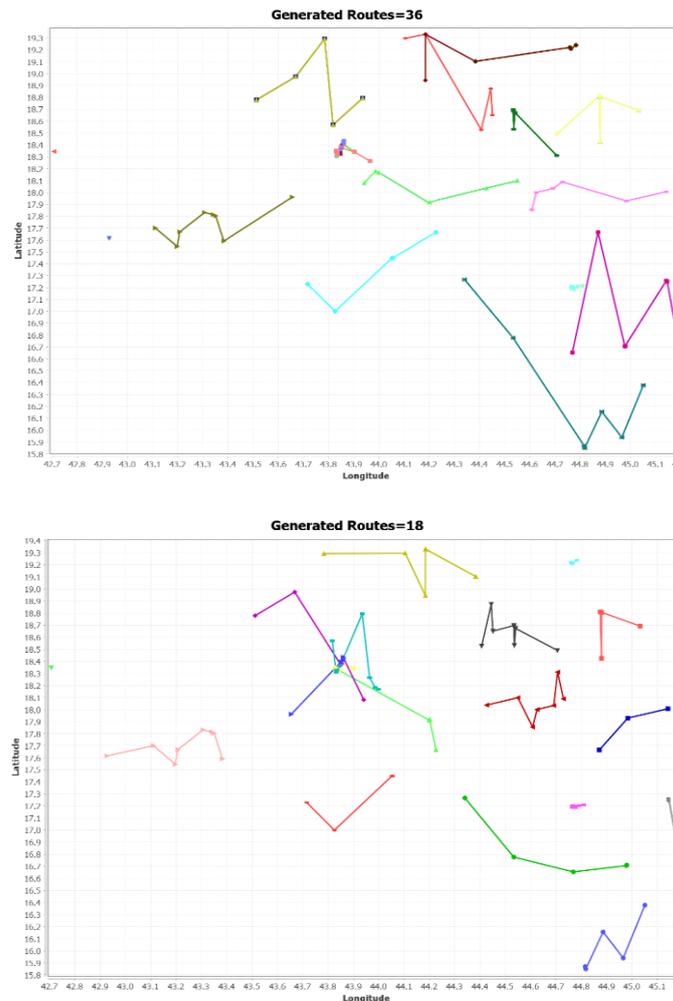


Fig. 8. Simple visual representation of the generated weekly routes for the delivery vehicle routing problem from the a) *ad hoc* approach, b) basic TSP approach, and c) clustering-based TSP approach.

4.3. Discussion

After the benchmarking results revealed significant improvement, there are two major implications that need to be discussed in the context of integration of the developed approaches: the technical implications and the much more important social implications.

4.3.1. Technical level implementation

As discussed in the previous section, the technical implementation has demonstrated good results and there is still room for further improvement. This goes to show that, especially in environments that are heavily dependent on specific constraints, the technical side is always susceptible to further improvement. Every day the algorithms are advancing and, rightfully so, the solutions utilizing them become bigger, faster, and more profitable for companies to implement. The more complex task, in both of the described case, is how to integrate these advanced functionalities so that all sides involved are contemptous.

4.3.2. Management level viewpoint

In order to find out how the warehouse employees are feeling about the introduced changes, especially in situations where their daily routines are changing, a series of informal conversations was carried out with people from various different position levels. Starting from the top, the people in charge of the strategic management of the company are usually the ones which set in motion the implementation of such systems

for various reasons. In the case of underdeveloped countries, those decisions are frequently made out of necessity than an actual wish for business improvement, e.g., because larger associate companies require a higher level of automation to continue the cooperation. Because a negative attitude and reluctance of the people ordering the system can cause a lot of problems during the development cycle, it is important to have an agile development approach and always be ready to showcase some of the advantages of the system. In this way, all the critics and sudden changes, which can hinder development, can be addressed promptly.

In the case of mid-level management, they play the biggest role during the integration phase. Although usually pessimistic about the promised improvements, they are very helpful because they are the only ones which can inspire or make the employees to try and do something differently than what they are used to. Because of this, a good communication and constant prototyping with these people is of utter importance. If they are contempt with the introduced changes, the operational level employees will also be more optimistic and open to trying new things. However, the lower the position on the governance ladder gets, the bigger the resistance to changes becomes. During the development cycle of the WMS in the representative routing case study, most changes were successfully implemented because of the good cooperation between developers, managers and warehouse employees.

4.3.3. Operational level viewpoint

The biggest challenge was finding a compromise with the warehouse employees and understanding their views on how things should work. There were a lot of misunderstandings during the initial implementation attempts, but a lot of crucial information was also extracted through this intensive communication. These people are the ones that will use the system in the end, and have an impact if it will be utilized to its maximum potential, so it is only natural to value and listen to their opinions. Otherwise, employees are going to struggle to use the system or just boycott the innovations in order revert back to their usual routines. Based on the communication with the employees, two main things stood out as problems:

1. The representatives could not see the immediate benefit of the new approaches and wanted to revert back to their old routines because they were "better" in their own opinion.
2. The managers did not pay enough attention, did not care and did not control the situation.

In order to find a fitting solution for these problems, the key step was a direct conversation combined with an illustrative and comparative approach. Namely, to demonstrate the benefits of the newly generated routes, the drivers were prompted to drive a test period of one week according to their old ways and one week according to the new approach. After this test period, meetings with the drivers that drove the routes were held and most of them admitted that the new routes made more sense in the long run, but seemed illogical at first which prompted them to feel negative and reject the newly introduced changes. Furthermore, there is a strategy for creating a set of test drivers. To get the most out of this comparative approach, it should target the most influential and respected workers in the company. Afterwards, via word of mouth and similar communication among the employees, the news about how good the system actually is will spread and the other workers will start to get at least intrigued. This will ease in the new approach into their everyday routines, which seemed unthinkable at first. If this is compared to a forced approach, which can render the improvements useless and create a collective rejection to changes, it is worth it in the end, even though it is a long process which requires social knowledge, very good communication skills, and a lot of experience in dealing with all personality types. In big projects, having experienced management staff can be the decisive factor whether the projects is a success or failure.

5. Conclusion and Future Work

This research highlighted a gradual strategy to the development of a novel routing approach through two

real-world case studies. Throughout these case studies, the technical as well as the social implications of the implementation of such a system were described. The experiments were intentionally designed to highlight both of these aspects and demonstrate the importance of proper communication. In the end, the route efficiency almost doubled and the employees were contempt with the newly introduced changes.

In conclusion, the main goal of this research was to introduce a novel routing approach, but more importantly to highlight the importance of the human factor during system development, especially during the integration process. It is a sensitive and crucial part of the project, which can cause whole projects to fail, even after a lot of resources and time was invested. The technical process can yield remarkable results, but if it is not properly utilized and actually used in practice, the main objective is not achieved. This is the reason why good communication and cooperation on all company levels is key for a successful implementation and integration of any system.

In the future, the main goal is to expand the newly acquired knowledge in the development of similar information systems which do not necessarily need to be related to warehouses which is partially demonstrated by the second case study. A generalization of rules and practices in systems where the development of advanced algorithms is prevalent, would be a great future direction.

Conflict of Interest

The authors declare no conflict of interest.

Author Contributions

This paper is result of great team collaboration. All authors worked together on each part of the paper. It included analysing of the available literature, collecting the data, conducting experiments, creating methods, results discussing, concluding and finally writing the paper. All authors had approved the final version.

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References

- [1] Karasek, J. (2013). An overview of warehouse optimization. *IJATES*, 2(3), 111-117.
- [2] Min, H. (2010). Artificial intelligence in supply chain management: Theory and applications. *Int. Jour. of Logistics*, 13(1), 13-39.
- [3] Gue, K. R., & Meller, R. D. (2009). Aisle configurations for unit-load warehouses. *IIE Trans.*, 41(3), 171-182.
- [4] Pohl, L. M., Meller, R. D., & Gue, K. R. (2009). Optimizing fishbone aisles for dual-command operations in a warehouse. *Nav. Res. Logist.*, 56(5), 389-403.
- [5] Sysoiev, V. (2013). Optimizing the number and location of warehouses in logistics networks considering the optimal delivery routes and set level of reserve stock. *Theory Methodology Practice (TMP)*, Faculty of Economics, Univ. of Miskolc, 9(2), 85-93.
- [6] Laporte, G. (2010). The travelling salesman problem, the vehicle routing problem, and their impact on combinatorial optimization. *Int. Jour. of Strategic Decision Sciences*, 1(2), 82-92.
- [7] Englert, M., Röglin, H., & Vöcking, B. (2007). Worst case and probabilistic analysis of the 2-Opt algorithm for the TSP: extended abstract. *Proceedings of the Eighteenth Annual ACM-SIAM Symposium on Discrete Algorithms* (pp. 1295-1304). New Orleans, Louisiana. SODA '07.
- [8] Mahi, M., Baykan, Ö. K., & Kodaz, H. (2015). A new hybrid method based on particle swarm

- optimization, ant colony optimization and 3-Opt algorithms for traveling salesman problem. *Applied Soft Computing*, 30, 484-490.
- [9] Yang, J., Shi, X., Marchese, M., & Liang, Y. (2008). An ant colony optimization method for generalized TSP problem. *Progress in Nat. Sci.*, vol. 18(11), 1417-1422.
- [10] Tinarut, P., & K. Leksakul (2019). Hybrid self-organizing map approach for traveling salesman problem. *Jour. of Nat. Sci.*, 18(1), 27-37.
- [11] Zhou, A. H., et al. (2018). Traveling-salesman-problem algorithm based on simulated annealing and gene-expression programming. *Information*, 10(7).
- [12] Anaya, F. G. E., Hernández, G. E. S., Seck, T. M. J. C., & Medina, M. J. (2018). Solution to travelling salesman problem by clusters and a modified multi-restart iterated local search metaheuristic. *PLoS ONE*, 13(8).
- [13] Ko, S. Y., Cho, S. W., & Lee C. (2018). Pricing and collaboration in last mile delivery services. *Sustainability*, 10(12), 45-60.
- [14] Chládek, P., & Smetanová, D. (2018). Travelling salesman problem applied to black sea ports used by czech ocean shipping companies. *Nase More*, 65(3), 141-145.
- [15] Vartdal, J. T., Qassim, R. Y., Mokliev, B., Udjus, G., & Gonzalez-Gorbena, E. (2019). Optimal configuration problem identification of electrical power cable in tidal turbine farm via traveling salesman problem modeling approach. *Journal of Modern Power Systems and Clean Energy*, 7(2), 289-296.
- [16] Lynskey, J., Thar, K., Oo, T. Z., & Hong, C. S. (2018). Facility location problem approach for distributed drones. *Symmetry*, 11(1), 118.
- [17] Zunic E., et al. (2017). Design of an optimization system for warehouse order picking in real environment. *Proceedings of XXVI International Conference on Information, Communication and Automation*.
- [18] Zunic, E., et al. (2017). Application of advanced analysis and predictive algorithm for warehouse picking zone capacity and content prediction. *Proceedings of XXVI International Conference on Information, Communication and Automation*.
- [19] Liao, Z. X., & Peng, W. C. (2012). Clustering spatial data with a geographic constraint: Exploring local search. *Knowl. Inf. Syst.*, 31(1), 153-170.
- [20] Ester, M., Kriegel, H. P., Sander, J., & Xu, X. (1996). A density-based algorithm for discovering clusters in large spatial databases with noise. *KDD'96 Proceedings of the Second Int. Conf. on Knowledge Discovery and Data Mining* (pp. 226-231).

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