Int j simul model 21 (2022) 2, 203-213
Original scientific paper

MAINTENANCE SCHEDULING OF HEATING NETWORKS USING SIMULATION IN WITNESS

Rodrigues, M. V. T.; Sirova, E. & Dyntar, J.
Technical University of Liberec, Faculty of Economics, Voronezska 13, 460 01 Liberec 1, Czech Republic
E-Mail: marcio.rodrigues@tul.cz, eva.sirova@tul.cz, jakub.dyntar@tul.cz

Abstract
Vehicle routing has become an important part of the maintenance scheduling mainly in case of the systems consisting of geographically dispersed facilities. In this paper we describe the efficient way to set the schedule of visits for technicians ensuring the preventive maintenance of heating networks. Our model consists of geographic information system, Clarke and Wright savings algorithm to obtain a single route by solving travelling salesman problem and discrete-event simulation to convert the single route to the schedules of visits. Our solution is suitable for applications in large scale systems where the regular preventive maintenance of a facility is required but the frequencies of visits of facilities are hazily specified and randomly distributed over the time. Based on the outputs coming from the simulation of a real heating network consisting of 550 heating facilities located in Prague, Czech Republic and adjacent suburban areas we discuss how the schedule of visits leading to the long-term service of a consolidated territory can positively affect the operational efficiency of the maintenance.
(Received in November 2021, accepted in February 2022. This paper was with the authors 1 week for 1 revision.)

Key Words: Preventive Maintenance, Maintenance Scheduling, Vehicle Routing, Discrete-Event Simulation, Witness

1. INTRODUCTION

Heating networks can be defined as systems of remote heating to serve a neighbourhood or city, which uses the heat produced from a thermal power plant, a cogeneration plant or a geothermal source [1]. In such system heat is distributed to buildings through pipes that carry hot water or steam [2]. The heart of the system is composed of one or more exchanges that can serve buildings located also to a few kilometres away [3].

Maintenance planning and scheduling is shown today as an essential part of any economic segment, requiring the use of increasingly skilful and effective processes. This concept has led maintenance to assume a new strategic posture, not only focusing on repairing equipment, but also defining strategic plans that aim to reduce the probability of an interruption in the offer of products or services and additional costs for companies [4-6]. The absence of maintenance or even an inefficient maintenance plan favours the process to point out unexpected variations and failures, demanding that those responsible must implement maintenance management models that are adequate to their reality, to ensure the quality of service provision [7, 8].

The maintenance policies can be divided into two basic groups: (1) corrective maintenance, and (2) preventive maintenance [9]. Corrective maintenance (CM) can be defined as the work that must be done after an item has failed or worn out in order to restore it to functioning order [10]. After an item fails, CM entails replacing or repairing it. CM tasks identify the problem and fix it so that the equipment can be repaired and the facility's production can resume. CM is often less expensive since it can be done with fewer resources and maintenance infrastructure, such as tools, technologies, and experience. However, it is inefficient and, in the long run, it can be quite costly because failures almost always result in serious outcomes. Preventive maintenance (PM) on the other hand can be described as a set of operations that predict the item's health status and identify when the appropriate time is to undertake the maintenance intervention to improve the item's reliability and availability [11]. PM is the technique of repairing or replacing components or subsystems before they break in order to maintain system availability or avert harmful or inconvenient failures. PM is planned based on prior system behaviour, component wear-out mechanisms, and knowledge of which components are critical to the system's continuous operation. In many cases, it is more cost-effective to replace parts or components at predefined intervals rather than waiting for a failure that could cause a costly interruption in operations.

Vehicle routing has become an important part of the maintenance scheduling mainly in case of the systems consisting of geographically dispersed facilities [12, 13]. Vehicle Routing Problem (VRP) is a combinatorial optimization whose main objective is to find routes, from a starting point (e.g. a warehouse or a depot), with equal vehicles, with the lowest possible cost to meet the demand of customers [14, 15]. Many variations of VRP such as capacitated VRP, VRP with time windows or VRP with multiple starting points are described in the scientific literature including applications in various fields of industry, see e.g. [16-18]. Traveling Salesman Problem (TSP) represents VRP with a single route and no vehicle capacity limitation [19]. As both VRP and TSP are NP-hard problems with a limited size of a problem that can be solved using mathematical programming or combinatorial optimization, heuristics such as genetic algorithm [20], tabu search [21], particle swarm optimization [22] or Clarke and Wright savings algorithm (CWS) [23] tend to be more appropriate when dealing with real life VRPs.

Due to its ease of implementation and quick computation speed, CWS is the most extensively used heuristic for solving capacitated VRP [24]. It's also being used as a basic algorithm in a lot of commercial routing software [25]. However at some situations it needs to be improved to prevent solutions that are too far from optimal one [26]. We suggest discrete-event simulation to be a great method to increase the performance of savings algorithm. Discrete-event simulation enables modelling a system as a discrete sequence of events using a computer [27]. Simulation provides a variety of advantages over other operational research approaches, including the capacity to speed up or slow down time to study a system over a longer period of time or to investigate its behaviour more closely [28].

The goal of this paper is to describe the efficient way to set the schedule of visits for workers ensuring the preventive maintenance of heating networks. Our model consists of geographic information system, Clarke and Wright savings algorithm to obtain a single route by solving travelling salesman problem and discrete-event simulation to convert the single route to the schedules of visits. Our solution is suitable for applications in large scale systems where the regular preventive maintenance of a facility is required but the frequencies of visits of facilities are hazily specified and randomly distributed over the time. Based on the outputs coming from the simulation of a real heating network consisting of 550 heating facilities located in Prague, Czech Republic and adjacent suburban areas we discuss how the schedule of visits leading to the long-term service of a consolidated territory can positively affect the operational efficiency of the maintenance.

2. SIMULATION FOR PREVENTIVE MAINTENANCE SCHEDULING OF HEATING NETWORKS WITH A SINGLE SERVICE DEPOT

2.1 Model description

Our model can be divided into 3 parts (see Fig. 1).

The first part called Geographic Information System (GIS) contains MS Excel custom function described in [29] to obtain road distances among heating facilities and a service depot. The code of the used custom function is shown in **Appendix 1**. The argument of the function (i.e. Origin and Destination) is in the form of the string including a street name, a land registry number/a house number and a city. As a web map service the function calls Google Maps API Directions platform preferring to return a distance representing the shortest route by a car.

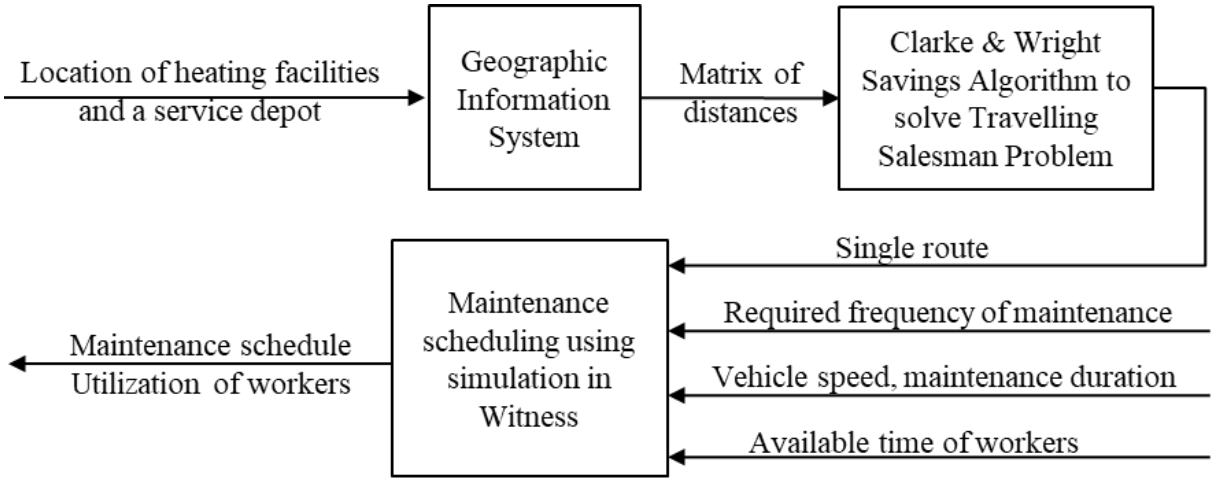

Figure 1: Simulation model of a heating network maintenance system.

The output coming from GIS in the form of a matrix of distances serves as an input for CWS that is applied to solve TSP. CWS is executed as Macro in MS Excel and consists of the following steps (see [23]):

1. Calculate savings $s(j, j')$ for each pair of heating facilities (j, j') with help of Eq. (1):

$$s(j, j') = d(D, j) + d(D, j') - d(j, j') \tag{1}$$

   where D represents a service depot and d represents a distance between heating facilities coming from the matrix of distances.

2. Sort savings $s(j, j')$ in descending order.

3. For the maximal available saving $s(j, j')$, add (j, j') to a route, if:

   a) Either, neither j nor j' is the part of a route, in this case new route is established with both j and j'.

   b) Or, one of j or j' is already the part of a route. In case that it is not placed within the route (j, j') is added to the same route.

   c) Or, both j and j' are the part of a route and none of these are placed within these routes, in that case these routes are merged.

4. If a saving $s(j, j') > 0$ is still available go back to 3.

The output of CWS represented by the single route is subsequently imported from MS Excel to simulation in Witness. Witness is a commercial simulation tool developed by Lanner Group Ltd. [30] with many applications in decision-making in production and logistics that are described in the literature, see e.g. [31, 32]. It contains pre-defined physical elements suitable for modelling various both discrete and continuous logistics systems. CWS output is imported via Initialize Actions and XLReadArray command together with information about required frequency of maintenance, vehicle speed, maintenance duration, available time of workers responsible for the maintenance and the matrix of distances. All input data in simulation is then available through Witness pre-defined elements called Variables. Maintenance scheduling itself is realized by 3 elements called Machine (see Fig. 2).

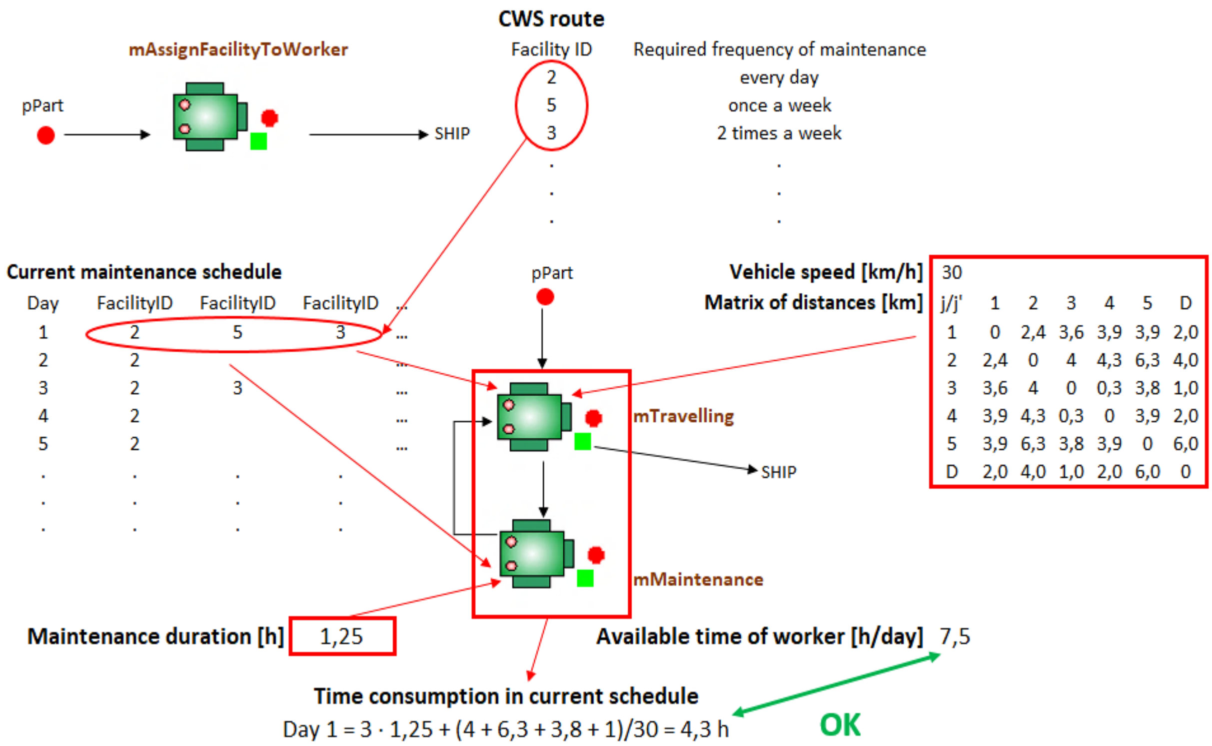

Figure 2: Maintenance scheduling using Witness elements called Machines.

First machine called mAssignFacilityToWorker adds heating facilities in a schedule according to their order in CWS route and required frequency of maintenance. If for example CWS route contains Facility ID 2, 5 and 3 with required frequency of maintenance specified as every day, once a week and 2 times a week and assuming one week to have 5 working days, the machine called mAssignFacilityToWorker adds these ID's step by step to variable representing Current maintenance schedule (see Fig. 2). When an ID is added to the schedule two Machines called mTravelling and mMaintenance simulate scheduled travelling and maintenance for each day and check whether the Time consumption in current schedule exceeds the Available time of a worker or not. Time of travelling is affected by the Vehicle speed and the distances among facilities. These distances are available in the Matrix of distances. Time of maintenance is affected by the number of visited facilities and the Maintenance duration. Whenever an ID added to the schedule causes an overrun of the Available time of worker the Machine called mMaintenance decides to remove it. As the number of facilities in the Current maintenance schedule and the utilization of the Available time of worker increase during the simulation run more and more facilities are removed. This is because of the impossibility to follow required frequency of maintenance, the prolonging distance that has to be travelled among facilities or the excessive time spent on maintenance. If no facility can be added, the Current maintenance schedule is exported to MS Excel via XLWriteArray command and the utilization of a worker is calculated. The simulation ends up in case that all facilities are in a schedule.

2.2 Simulation of a real system

The model described in previous chapter is applied to schedule the maintenance of a real heating network. The network consists of 550 heating facilities located in Prague, Czech Republic and adjacent suburban areas. For each heating facility the address accurately describing its location and required frequency of maintenance are provided by the company executing regular preventive maintenance of the system (see Table I).

Table I: Location of heating facilities and required frequency of maintenance (sample).

Facility ID	**Facility location**	**Required frequency of maintenance**
2	Janského 2367/97, Praha 13 - Stodůlky	once in two weeks
15	Vodnická 422/45, Praha - Újezd	daily
62	Náhorní 525/1, Praha 8 - Kobylisy	once a week
63	Mikuláše z Husí 1522/2, Praha 4 - Nusle	once a week
321	Novovysočanská 501/5, Praha 9 - Vysočany	once a month
323	U Starého stadionu 1585/9, Praha 16 - Radotín	once a month
511	Evropská 1973/56, Praha 6 - Dejvice	twice a week

Based on required frequency of maintenance and assuming one week to have 5 working days and one month to have 20 working days the probability distribution of a time between two visits of a heating facility is set (see Fig. 3).

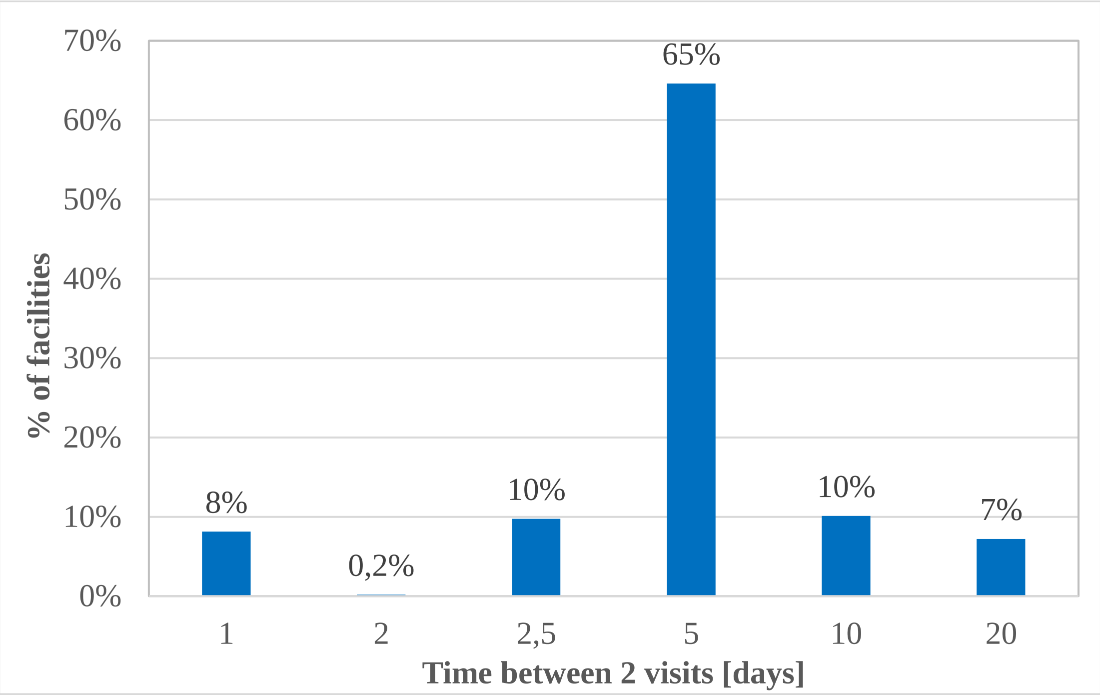

Figure 3: Probability distribution of a time between two visits of a heating facility.

It can be seen that the majority of facilities (i.e. 65 %) are visited once a week. Based on the longest time between two visits of a heating facility the scheduling period is decided to be 20 days. Available time of a worker responsible for the maintenance is 7,5 h/day assuming on shift time to range from 8:00 to 16:00, from Monday to Friday. This is in accordance with the company standards currently operating the maintenance system. Together with the locations of facilities and required frequency of maintenance this company also provided the e-Logbook with the history of heating facilities visits of 22 workers responsible for maintenance during 9/2021. Average maintenance duration in this period is 44,1 min/visit while total travelling time of workers is 561 h/month. Service depot is located in Běhounkova 2452/6, Praha 13 – Stodůlky. To obtain the matrix of distances Google Maps API Directions platform was queried on 05. 10. 2021. Because the real average speed of vehicle depends highly on a current traffic situation we simulate 9 different scenarios. In these scenarios the average speed of vehicle ranges from 10 to 50 km/h with a step of 5 km/h. To carry out simulations MS Excel 16, Witness 14 and computer with the processor Intel Core i7 – 2,8 GHz, 16 GB RAM are used.

2.3 Simulation results

Fig. 4 shows required number of workers executing the maintenance of heating facilities and the time spent on travelling among them.

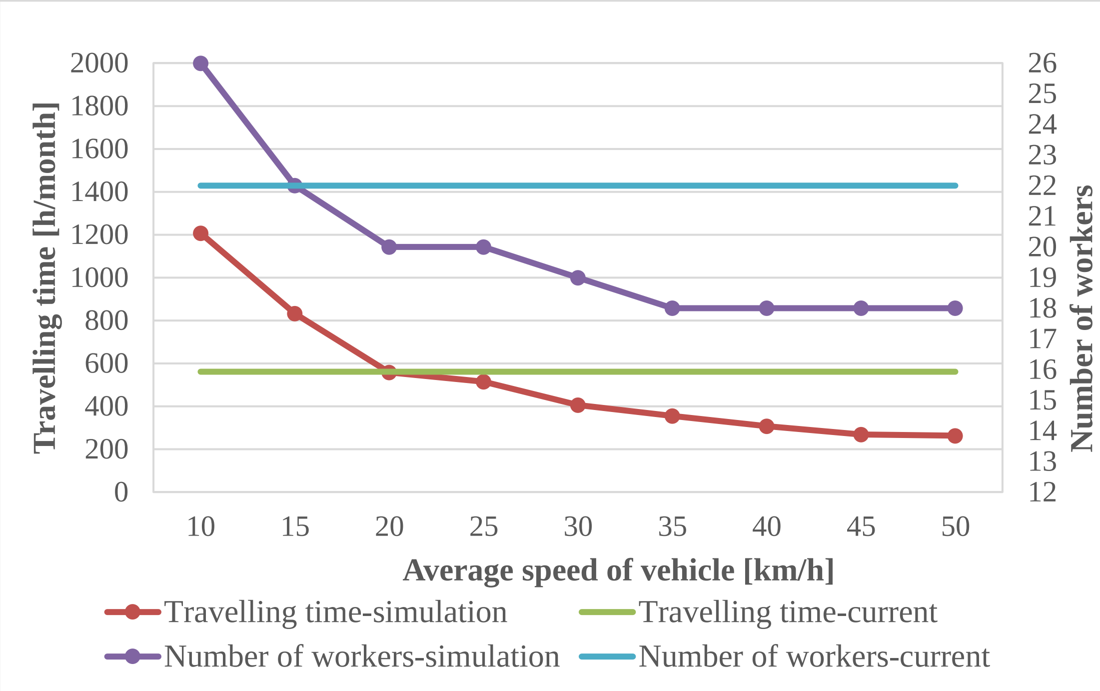

Figure 4: Simulation outputs – travelling time and number of workers.

For scenarios with the average speed of vehicle 10 and 15 km/h our model does not reach any savings of workers when compared to current state (i.e. 22 workers). For average speeds ranging from 20 to 50 km/h number of workers is reduced by 2 – 4. This is caused mainly by the significant decrease of travelling time (i.e. 1-53 % for average speeds 20-50 km/h) but also by the more efficient allocation of heating facilities among workers leading to their higher utilization (see Fig. 5).

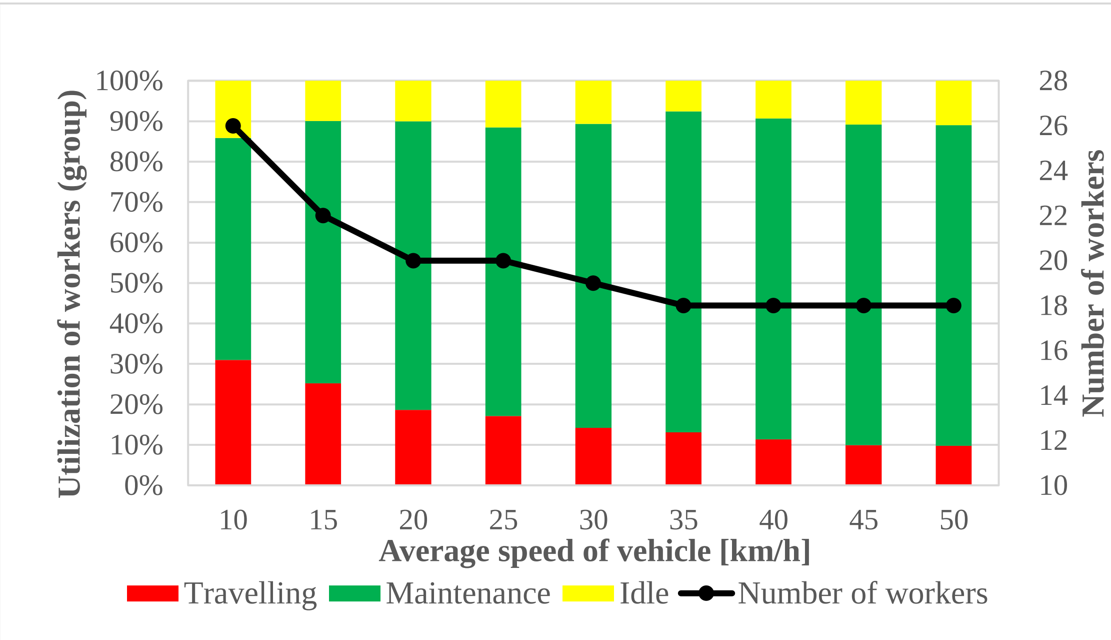

Figure 5: Simulation outputs – utilization of workers.

Based on the outputs in Fig. 5 the utilization of the group of workers is stabilized around 90 %.

Table II shows an example of the maintenance schedule coming from the simulation scenario with the average speed of vehicle 30 km/h.

Table II: Simulation outputs – example of maintenance schedule (average speed of vehicle 30 km/h).

Day	Travelling [h]	Maintenance [h]	Distance [km]	Visited facilities	Scheduled route - Facility ID's						
1	1,6	5,1	48	7	470	363	444	308	310	94	168
2	1,5	4,4	46	6	251	362	115	451	309	80	-
3	1,6	5,1	47	7	174	335	364	225	324	93	170
4	1,6	5,1	48	7	176	334	447	462	306	205	169
5	1,5	5,1	45	7	175	223	286	189	307	305	101
6	1,6	5,1	48	7	470	363	444	308	310	94	168
7	2,1	5,1	62	7	251	362	115	451	309	80	312
8	1,6	5,1	47	7	174	335	364	225	322	93	170
9	1,6	5,1	48	7	176	334	447	462	306	205	169
10	1,5	5,1	45	7	175	223	286	189	307	305	101
11	1,6	5,1	48	7	470	363	444	308	310	94	168
12	2,1	5,1	62	7	251	362	115	451	309	80	312
13	1,6	5,1	47	7	174	335	364	225	325	93	170
14	1,6	5,1	48	7	176	334	447	462	306	205	169
15	1,5	5,1	45	7	175	223	286	189	307	305	101
16	1,5	5,1	46	7	470	363	444	308	323	310	94
17	1,6	5,1	49	7	251	362	115	451	309	80	168
18	1,5	5,1	46	7	174	335	364	225	326	93	170
19	1,6	5,1	48	7	176	334	447	462	306	205	169
20	1,5	5,1	45	7	175	223	286	189	307	305	101

For each day the number of heating facilities to be visited by a worker (i.e. 6 or 7 in Table II) and their order in a route are scheduled. It can be seen that the worker starts his/her route on day 1 at the facility with ID = 470, then continues to the facility with ID = 363 and ends up the day 1 route in the facility with ID = 168. The order of facilities in a scheduled route tends to be correlated as much as possible to TSP solution obtained by CWS ensuring maximal savings of the distance travelled. If a heating facility is added to the schedule outside the TSP solution it is forced by the required frequency of preventive maintenance exceeding available time of a worker while a next facility in order add-in is permitted leading to the maximization of a worker utilization. Based on the number of facilities to be visited during a day total time spent on maintenance is calculated (i.e. 4,4 – 5,1 h in Table II). Based on the route consisting of the facilities to be visited during a day and the matrix of distances coming from GIS total distance is calculated (i.e. 45 – 62 km in Table II) assuming to start and finish a route in the depot. The total distance is recalculated to total time spent on travelling (i.e. 1,5 – 2,1 h in Table II) with help of the average speed of vehicle. Based on the schedule shown in Table II the worker is responsible for the maintenance of 39 facilities.

Fig. 6 shows the consumption of computational time to obtain the maintenance schedule. The most demanding part of our simulation in term of the time consumption represents the generation of the matrix of distances (almost 2 h). Searching for TSP solution using CWS takes approximately 1 h. And finally one simulation run in Witness environment to obtain a maintenance schedule and related outputs is quite efficient taking less than 0,5 min.

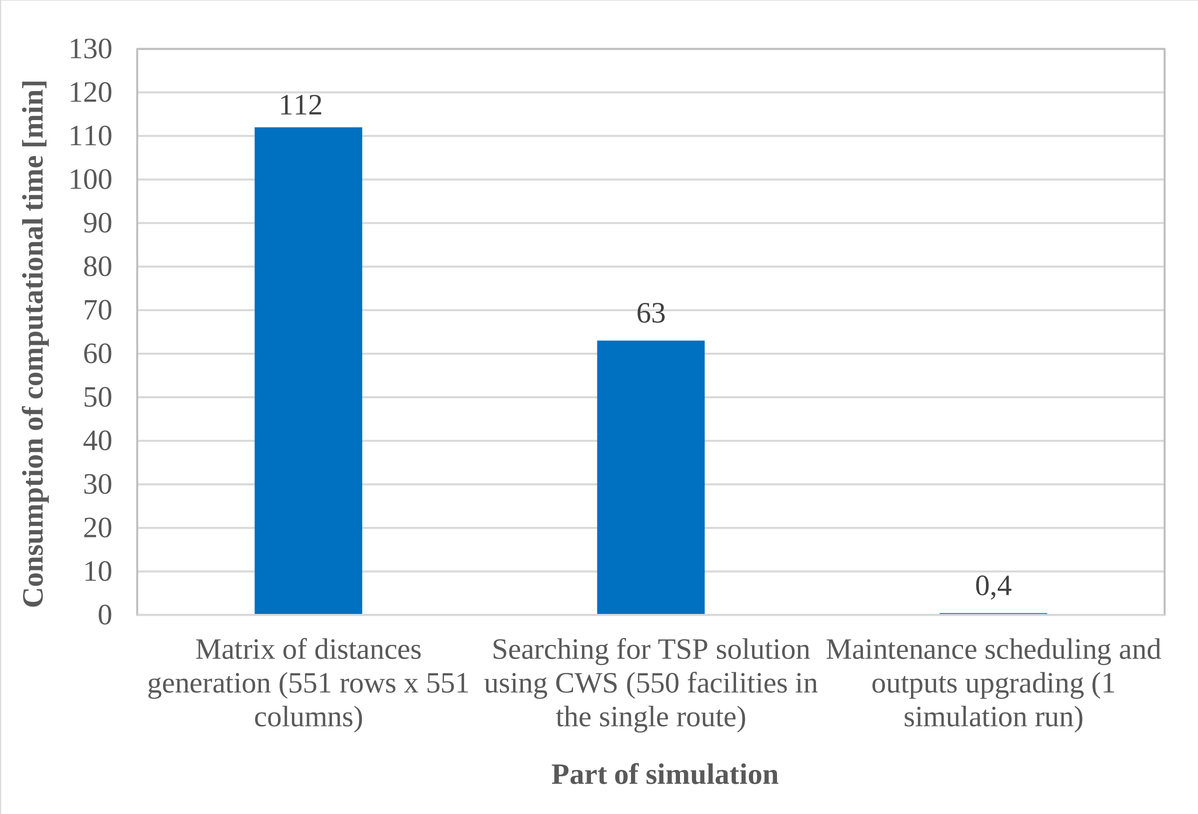

Figure 6: Consumption of computational time in our simulation.

3. CONCLUSION

Maintenance scheduling has a significant influence on the reliability and availability of assets, as unintentional failures are avoided. Geographically dispersed facility maintenance scheduling has been studied in a competitive business area for the past decade because of the importance of the subject for reducing costs and improving customer satisfaction. However, there is still an urgent need to investigate the neglected aspects of these types of problems. The goal of this paper is to describe the efficient way to set the schedule of visits for technicians ensuring the preventive maintenance of heating networks. The results of the simulation of the real heating network consisting of 550 heating facilities located in Prague, Czech Republic and adjacent suburban areas prove that our model is suitable for the regular preventive maintenance scheduling in the systems with geographically distributed assets where efficient vehicle routing represents important part of optimization. We consider our solution to be innovative because we solve VRP combining CSW to solve TSP with the simulation in Witness to convert the single route to consolidated territories (i.e. one worker visits repeatedly the same set of objects that are inflated in relatively tight geographical areas) in situations when the required frequencies of regular preventive maintenance of facilities are hazily specified and randomly distributed over the time. In maintenance scheduling, the above described approach to the vehicle routing brings numerous advantages from the operational efficiency point of view. Repeated visits of facilities deepen the knowledge about the traffic and parking situation in the area, accelerates the access to objects and also reduces the time spent on the maintenance because of previous experience with installed technology and resulting need for spare parts and equipment. The territories are assigned to workers according to their confirmed place of stay which is useful when the owners of facilities together with the preventive maintenance demand emergency service during off-shift time (i.e. generally in night and during the weekend). In this case the territories are usually merged into more extensive areas and workers take emergency turns guaranteeing required on call travel time to an object with the occurrence of random failure. Moreover job accessibility in term of travel time is considered to be one of the significant factors influencing the fluctuation of workers (see e.g. [33]) which can be crucial especially if the unemployment rate is low.

From the consumption of computational time point of view our solution is powerful enough and therefore suitable for frequent application in large-scale systems (hundreds or even thousands of objects) and does not require any above standard hardware equipment. Furthermore, CSW application avoids possible investments to a solver when VRP involves the design of a mixed integer linear programming model. Matrix of the distances can be updated continuously as new or contemporary maintained objects are added to or removed out of a scheduled system leading to the significant reduction of queries sent to the web map service. The relatively low number of physical elements used in the discrete-event simulation part has a beneficial influence on the speed of its execution and can be simply moved to an alternate simulation environment such as Simul8 [34], Arena [35], or even completely to spreadsheets, avoiding the need to invest in simulation software.

We see the possible future development of our model in the integration of maintenance scheduling with modelling and optimization of warehouse processes linked with receiving, storing, picking and expedition of spare parts based on spare parts demand planning.

REFERENCES

[1] Yang, X.; Svendsen, S. (2018). Ultra-low temperature district heating system with central heat pump and local boosters for low-heat-density area: analyses on a real case in Denmark, *Energy*, Vol. 159, 243-251, doi:10.1016/j.energy.2018.06.068

[2] Zavrl, E.; Zupanc, G.; Stritih, U.; Dovjak, M. (2020). Overheating reduction in lightweight framed buildings with application of phase change materials, *Strojniski vestnik – Journal of Mechanical Engineering*, Vol. 66, No. 1, 3-14, doi:10.5545/sv-jme.2019.6244

[3] Huang, J.; Li, Z.; Wu, Q. H. (2017). Coordinated dispatch of electric power and district heating networks: a decentralized solution using optimality condition decomposition, *Applied Energy*, Vol. 206, 1508-1522, doi:10.1016/j.apenergy.2017.09.112

[4] Zeng, P.; Shao, W.; Hao, Y. (2021). Study on preventive maintenance strategies of filling equipment based on reliability-cantered maintenance, *Technical Gazette*, Vol. 28, No. 2, 689-697, doi:10.17559/TV-20190404054849

[5] Froger, A.; Gendreau, M.; Mendoza, J. E.; Pinson, E.; Rousseau, L.-M. (2016). Maintenance scheduling in the electricity industry: a literature review, *European Journal of Operational Research*, Vol. 251, No. 3, 695-706, doi:10.1016/j.ejor.2015.08.045

[6] Al-Refaie, A.; Al-Shalaldeh, H.; Lepkova, N. (2020). Proposed procedure for optimal maintenance scheduling under emergent failures, *Journal of Civil Engineering and Management*, Vol. 26, No. 4, 396-409, doi:10.3846/jcem.2020.12315

[7] Xu, D.; Yin, Y.; Li, H. (2010). Scheduling jobs under increasing linear machine maintenance time, *Journal of Scheduling*, Vol. 13, No. 4, 443-449, doi:10.1007/s10951-010-0182-0

[8] Shin, J.-H.; Jun, H.-B. (2015). On condition based maintenance policy, *Journal of Computational Design and Engineering*, Vol. 2, No. 2, 119-127, doi:10.1016/j.jcde.2014.12.006

[9] Rashidnejad, M.; Ebrahimnejad, S.; Safari, J. (2018). A bi-objective model of preventive maintenance planning in distributed systems considering vehicle routing problem, *Computers & Industrial Engineering*, Vol. 120, 360-381, doi:10.1016/j.cie.2018.05.001

[10] Zhang, Z.; Tang, Q.; Chica, M. (2021). Maintenance costs and makespan minimization for assembly permutation flow shop scheduling by considering preventive and corrective maintenance, *Journal of Manufacturing Systems*, Vol. 59, 549-564, doi:10.1016/j.jmsy.2021.03.020

[11] Moghaddam, K. S.; Usher, J. S. (2011). Sensitivity analysis and comparison of algorithms in preventive maintenance and replacement scheduling optimization models, *Computers & Industrial Engineering*, Vol. 61, No. 1, 64-75, doi:10.1016/j.cie.2011.02.012

[12] Irawan, C. A.; Ouelhadj, D.; Jones, D.; Stalhane, M.; Sperstad, I. B. (2017). Optimization of maintenance routing and scheduling for offshore wind farms, *European Journal of Operational Research*, Vol. 256, No. 1, 76-89, doi:10.1016/j.ejor.2016.05.059
[13] Dhahri, A.; Zidi, K.; Ghedira, K. (2015). A variable neighborhood search for the vehicle routing problem with time windows and preventive maintenance activities, *Electronic Notes in Discrete Mathematics*, Vol. 47, 229-236, doi:10.1016/j.endm.2014.11.030
[14] Lopez-Santana, E.; Akhavan-Tabatabaei, R.; Dieulle, L.; Labadie, N.; Medaglia, A. L. (2016). On the combined maintenance and routing optimization problem, *Reliability Engineering & System Safety*, Vol. 145, 199-214, doi:10.1016/j.ress.2015.09.016
[15] Madankumar, S.; Rajendran, C. (2018). Mathematical models for green vehicle routing problems with pickup and delivery: a case of semiconductor supply chain, C*omputers & Operations Research*, Vol. 89, 183-192, doi:10.1016/j.cor.2016.03.013
[16] Goel, A.; Meisel, F. (2013). Workforce routing and scheduling for electricity network maintenance with downtime minimization, *European Journal of Operational Research*, Vol. 231, No. 1, 210-228, doi:10.1016/j.ejor.2013.05.021
[17] Zamorano, E.; Stolletz, R. (2017). Branch-and-price approaches for the multiperiod technician routing and scheduling problem, *European Journal of Operational Research*, Vol. 257, No. 1, 55-68, doi:10.1016/j.ejor.2016.06.058
[18] Ghannadpour, S. F.; Noori, S.; Tavakkoli-Moghaddam, R.; Ghoseiri, K. (2014). A multi-objective dynamic vehicle routing problem with fuzzy time windows: Model, solution and application, *Applied Soft Computing*, Vol. 14, Part C, 504-527, doi:10.1016/j.asoc.2013.08.015
[19] Mosayebi, M.; Sodhi, M.; Wettergren, T. A. (2021). The traveling salesman problem with job-times (TSPJ), *Computers & Operations Research*, Vol. 129, Paper 105226, 12 pages, doi:10.1016/j.cor.2021.105226
[20] Gocken, T.; Yaktubay, M. (2019). Comparison of different clustering algorithms via genetic algorithm for VRPTW, *International Journal of Simulation Modelling*, Vol. 18, No. 4, 574-585, doi:10.2507/IJSIMM18(4)485
[21] Lai, D. S. W.; Demirag, O. C.; Leung, J. M. Y. (2016). A tabu search heuristic for the heterogeneous vehicle routing problem on a multigraph, *Transportation Research Part E: Logistics and Transportation Review*, Vol. 86, 32-52, doi:10.1016/j.tre.2015.12.001
[22] Wu, D. Q.; Dong, M.; Li, H. Y.; Li, F. (2016). Vehicle routing problem with time windows using multi-objective co-evolutionary approach, *International Journal of Simulation Modelling*, Vol. 15, No. 4, 742-753, doi:10.2507/IJSIMM15(4)CO19
[23] Clarke, G.; Wright, J. W. (1964). Scheduling of vehicles from a central depot to a number of delivery points, *Operations Research*, Vol. 12, No. 4, 568-581, doi:10.1287/opre.12.4.568
[24] Altınel, İ.; Öncan, T. (2005). A new enhancement of the Clarke and Wright savings heuristic for the capacitated vehicle routing problem, *Journal of the Operational Research Society*, Vol. 56, No. 8, 954-961, doi:10.1057/palgrave.jors.2601916
[25] Juan, A. A.; Faulín, J.; Jorba, J.; Riera, D.; Masip, D.; Barrios, B. (2011). On the use of Monte Carlo simulation, cache and splitting techniques to improve the Clarke and Wright savings heuristics, *Journal of the Operational Research Society*, Vol. 62, No. 6, 1085-1097, doi:10.1057/jors.2010.29
[26] Pichpibul, T.; Kawtummachai, R. (2012). An improved Clarke and Wright savings algorithm for the capacitated vehicle routing problem, *ScienceAsia*, Vol. 38, No. 3, 307-318, doi:10.2306/scienceasia1513-1874.2012.38.307
[27] Agalianos, K.; Ponis, S. T.; Aretoulaki, E.; Plakas, G.; Efthymiou, O. (2020). Discrete event simulation and digital twins: review and challenges for logistics, *Procedia Manufacturing*, Vol. 51, 1636-1641, doi:10.1016/j.promfg.2020.10.228
[28] Straka, M.; Spirkova, D.; Filla, M. (2021). Improved efficiency of manufacturing logistics by using computer simulation, *International Journal of Simulation Modelling*, Vol. 20, No. 3, 501-512, doi:10.2507/IJSIMM20-3-567
[29] Dyntar, J.; Strachotova, D.; Botek, M. (2020). Adjusting direct distance to road for V4 countries, *Acta Logistica*, Vol. 7, No. 2, 85-93, doi:10.22306/al.v7i2.161
[30] Lanner Group Ltd. Witness Horizon, from *https://www.lanner.com/en-us/technology/witness-simulation-software.html*, accessed on 30-10-2021

[31] Fedorko, G.; Molnar, V.; Honus, S.; Neradilova, H.; Kampf, R. (2018). The application of simulation model of a milk run to identify the occurrence of failures, *International Journal of Simulation Modelling*, Vol. 17, No. 3, 444-457, doi:10.2507/IJSIMM17(3)440
[32] Wang, Q.-Z.; Chen, J.-M.; Tseng, M.-L.; Luan, H.-M.; Ali, M. H. (2020). Modelling green multimodal transport route performance with Witness simulation software, *Journal of Cleaner Production*, Vol. 248, Paper 119245, 12 pages, doi:10.1016/j.jclepro.2019.119245
[33] Liu, D.; Kwan, M.-P. (2020). Measuring spatial mismatch and job access inequity based on transit-based job accessibility for poor job seekers, *Travel Behaviour and Society*, Vol. 19, 184-193, doi:10.1016/j.tbs.2020.01.005
[34] SIMUL8 Corporation. SIMUL8 – Process Simulation Software, from *https://www.simul8.com*, accessed on 31-10-2021
[35] Rockwell Automation. Arena Simulation Software, from *https://www.arenasimulation.com/*, accessed on 31-10-2021

Appendix 1

```
Function Function2(Origin As String, Destination As String) As Double
    Dim myRequest As XMLHTTP60
    Dim myDomDoc As DOMDocument60
    Dim distanceNode As IXMLDOMNode
     On Error GoTo exit
      Origin = WorksheetFunction.EncodeURL(Origin)
      Destination = WorksheetFunction.EncodeURL(Destination)
      Set myRequest = New XMLHTTP60
      myRequest.Open "GET", "https://maps.googleapis.com/maps/api/directions/xml?" _
      & "&origin=" & Origin & "&destination=" & Destination & "&sensor=false" &
      "&key=***************************************", False
      myRequest.send
      Set myDomDoc = New DOMDocument60
       myDomDoc.LoadXML myRequest.responseText
      Set distanceNode = myDomDoc.SelectSingleNode("//leg/distance/value")
       If Not distanceNode Is Nothing Then Function2 = distanceNode.Text / 1000
    exit:
      Set distanceNode = Nothing
      Set myDomDoc = Nothing
      Set myRequest = Nothing
End Function
```