UDC 658.511 **doi: 10.20998/2078-7405.2022.96.04**

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OPTIMISATION OF MILKRUN ROUTES IN MANUFACTURING SYSTEMS IN THE AUTOMOTIVE INDUSTRY

Abstract. *The in-plant supply has a great impact on the performance of manufacturing operation, because the manufacturing-related logistics operations influence the efficiency of manufacturing. There are different solutions to perform in-plant supply, in the automotive industry the milkrun and water spider solutions are widely used. Within the frame of this article the authors describe the optimization of milkrun routes in the manufacturing plant of an automotive supplier. The described methodology simplifies the problem for single- and multi-milkrun problems and the solution is demonstrated with an Excel Solver-based methodology. The optimization process and its practicability will be demonstrated through an example.*

Keywords: *milkrun;optimization; logistic process; automobile industry.*

1. INTRODUCTION

The permanently increased demands of customers are significantly changing the role and operation of the automotive industry. Already since the second half of the 20th century, the flexibility of automotive processes and the minimisation of these processes over time become more and more important. In the logistics systems of automotive suppliers, long lead times are linked to production logistics processes, and all companies are therefore trying to find suitable solutions and reduce the lead time of production logistics. Milkrun solutions can be considered as suitable solutions of this problem of automotive industry. Milkrun is a system for the replenishment of raw materials at specific time, in varying quantities but, as a matter of principle, in similar sizes. In fact, it means the scheduled delivery and replenishment of raw materials and components used in production The advantage of milkrun systems is that the trolleys used to implement them can be flexibly extended and, in addition to the supply of raw materials, they can also transport the waste and scrap generated in production, i.e. a raw material cycle can be established [1-3]. In this paper, the authors present an optimization algorithm that is suitable for the design of complex milkrun-based material supply systems in industrial environments. In this paper, a solution method is presented using a practical example of an automotive supplier, which uses the capabilities of Excel Solver for batch execution to determine the optimal design of a large-scale in-plant supply chain for a milkrun system.

2. LITERATURE REVIEW

The literature on the design of milkrun-based material supply systems has expanded over the last decade, due to the increasing application of these solutions in industry, especially in mechatronics assembly and automotive supplier environments [4]. Since the aim of this paper is to present a methodology for the design of milkrun-based material supply systems, in this literature review we briefly review the main sources that provide a survey of the design methods and the main algorithms used in the design. It can be clearly stated that the design of milkrun-based material supply systems can be implemented using essentially heuristic algorithms due to their complexity. An optimization method based on a genetic algorithm is presented using the example of an automotive supplier to illustrate the solution of an NP-hard mixed integer programming problem [5]. A hybrid metaheuristic solution based on a harmony search and simulated annealing forms the basis of the algorithm discussed in [6]. This approach is used to show an example of supply chain optimization involving an off-site milkrun material supply system and a crossdocking facility. An example of the application of the C-W saving algorithm can be found in source [7], where a design method that minimizes the path length of the runs and the operating cost is described. The applicability of the ant colony algorithm is illustrated in [8] through an example of a dynamic optimization problem. In the example presented, minimizing the required time of material supply tasks is included as a main objective function component. A two-phase metaheuristic algorithm based on greedy and tabu search is used as the basis for the design method presented in [9], which aims at selecting optimal vehicles in high density milkrun material supply systems. An example of the application of evolutionary strategies is presented in [10]. The uniqueness of the presented example lies in the fact that the design of the milkrun material supply system integrates the inverse processes of the packaging materials, which is an integral part of both the in-plant and the external milkrun processes [12]. Of course, in addition to heuristic solutions, a number of simulation-based applications can also greatly support the design of milkrun systems [13-16]. Following this brief literature review, the paper presents the optimisation problem. Then, the optimization of the milkrun path for one or more milkrun-routes is described.

3. THE OPTIMISATION PROBLEM

The optimisation algorithm was created in Excel using the Excel Solver extension and the VBA (Visual Basic Application) development environment. Within the frame of this article both the algorithm and a numerical example is described. The parameters of the numerical example are the followings:

- 26 production lines (marked with “A” on the layout),
- 18 junctions (marked with “I” on the layout),

- the departure and arrival locations of the warehouse (marked with “WH” on the layout),
- the straight sections connecting these production lines, junctions and warehouse points.

In this scenario, the algorithm considers the size and capacity of the production lines to be the same. The length of the sections is a ratio without units of measure. The transportation time required per unit section is 3 seconds, and the time required for material handling (loading and unloading) at each production line is 10 seconds.

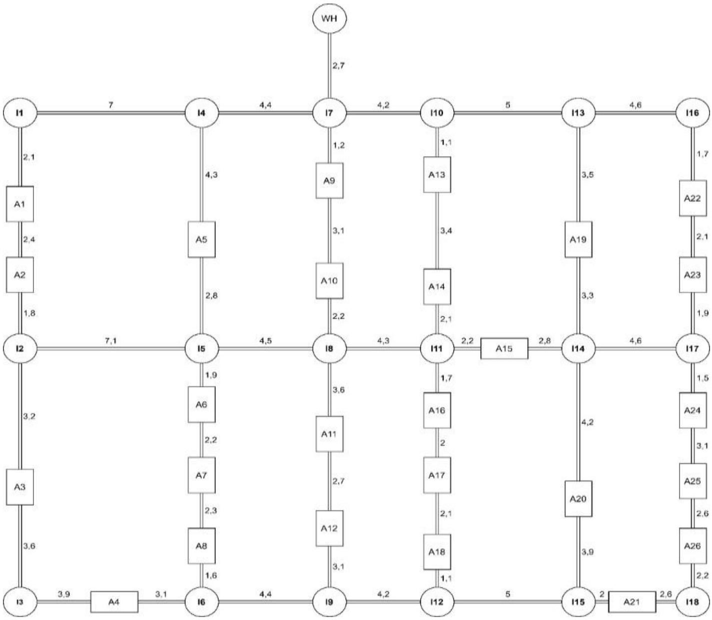

Figure 1 – Layout of the production plant

The main objective function of the optimization is the minimization of required time for the milkrun routes, while this optimised route satisfies the conditions necessary to perform the material handling tasks:

- The time required to travel the generated routes must not exceed the predefined upper time limit of the milkrun system. The predefined time limits may depend on the human resource (e.g. lunch break, end of working hours) or on technical or logistics resources (e.g. low battery). In the present numerical example, the predefined upper limit of the milkrun system is 500 seconds. In case the time required for the route exceeds the predefined time limit, the number of milkrun routes has to be increased and the optimisation has to be performed again.

- The number of milkrun routes can only be increased until the required quantity of logistics resources (milkrun trolley) does not exceed the available number of milkrun trolleys. In the case where all available trolleys have been used but our time constraint condition is not met, the task is unsolvable because of time- and capacity-related constraints.

To determine a path minimized as a function of time, the extreme value of the single-variable function must be determined, i.e., after derivation, the value of the derived function is 0.

$$f'(t) = 0 \tag{1}$$

There is a direct proportionality between the value of time and the value of distance (1 path unit → 3 s), so the time-dependent function and the distance-dependent function differ only in constant. Since the derivative of the constant is 0, it is sufficient to optimize the path by distance to minimize the time.

$$f(t) = g(s) * c \text{ and } f'(t) = g'(s) \tag{2}$$

Hence, the optimization method works with distance values, only converting the disctane values to time values at the end of the optimisation process.

4. SINGLE-MILKRUN OPTIMISATION

When optimising for a single route, our most important constraints are the followings: (1) the initial location and the final location of each milkrun routes is the warehouse, (2) the required materials are delivered or dropped out at the different production lines exactly once. The first step is to convert the identifiers of the production lines and the warehouse point into numbered identifiers. This is necessary because the Solver extension can only optimize with numeric conditions, not with other identification conditions. The conversion is outlined in Table 1.

Table 1 – Examples for the identification of production lines

ID of production line	WH	A1	A2	A3	A4	A5
No. ID of production line	0	1	2	3	4	5

After the identifiers have been converted, all possible paths connecting two production lines (or a production line and a storage point) should be entered in the Excel spreadsheet. An identifier must also be assigned to these sections, because the optimisation of the milkrun routes is based on the transformation of these sections. The identifier of the stages is the identifier of the outbound production line and the identifier of the inbound production line, linked by a hyphen. It is important to note that this is a directed graph, so both endpoints of an edge can be head or tail, so each edge must be taken into consideration twice.

Once the data and conditions for the optimisation have been defined, the actual optimisation is carried out.

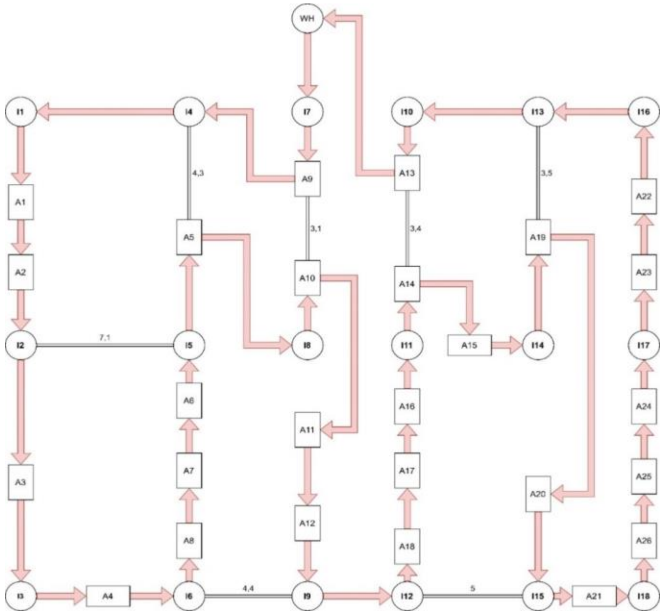

Figure 2 – Results of a single-milkrun optimisation

In the Solver interface, the following parameters are required for the optimisation:

- Value of the objective function: the cell in which the lengths of the given edges are summed.
- Objective: Minimization.
- Variables: The cells that can be varied to achieve the optimal result. In the present case, these variables are the numerical identifiers of production lines, because by changing them we can minimize the length of the route.
- Constraints: Specification of the conditions is necessary to perform the optimisation task. In out numerical example the following conditions are taken into consideration:

- The value of the cells defining the numerical identifiers of production lines is between 0 and 27.
- The required materials are delivered or dropped out at the different production lines exactly once, so each cell must have a different value (permutation representation).
- Solution method: Evolutionary.

Using the evolutionary solution method, the Solver finds the optimal solution of the milkrun routing problem within the frame of *n* phases. In the first phase, it selects the optimal solution from a random set of input values (locale optimum). From this selected set of solutions, in a second phase, it generates new solution sets and selects the optimal value. This algorithm is repeated until the solver cannot refine the solution within a given time parameter (iterative methodology). After all parameters are specified, the Solver outputs the result shown in Figure 2 as the optimal milkrun route. The most important parameters of the optimal route are the followings: length of the route is 141.9 distance unit, required time is 425.7 seconds, idle time is 260 seconds and total required time is 685.7 seconds. The total required time exceeds the predefined upper time limit, so the optimisation process must be extended with more milkrun trolleys.

5. MULTI-MILKRUN OPTIMISATION

Definition of the shortest path

Due to the fact that the result of the optimization for one milkrun route does not meet the predefined milkrun time constraint, the optimization must be performed for two milkrun routes. The first step is to determine the shortest route from the warehouse to each production line. This also requires the use of the Excel Solver extension, but determining the shortest paths to 26 production lines manually would take a lot of time, so VBA is used for batch optimization so that all the shortest paths can be determined in one step.

The optimisation requires a table of all possible routing paths. In contrary to the previous minimisation, in this phase not the edges between two production lines but the edges between the production line and the junction are taken into consideration. For each routing section, we assign its distance and a binary number. This binary number indicates whether or not the section is part of the desired shortest route. The length of the shortest route can be determined from this information multiplying the two numerical values of each route segment. Those sections that are not included in the route are eliminated by multiplying by 0. This value is minimized by the Solver. The minimization is done by varying the binary values of the route sections while constraints are taken into consideration. To specify the constraints, it is necessary to define a new table in which the starting point, the junctions and the production lines are listed. The constraint of the optimisation problem is that the initial location (the tail of the edge) is set to 1, the arrival point (the head of the edge) is set to -1, and all other production lines and junctions are set to 0.

The value of the points is given by the fact that each departure gives a value of 1 and each arrival a value of -1. The production lines or junctions, through which the route passes are both tail and head of the edges in the graph, so they sum is 0, as do the production lines or junctions through which the route does not pass. We should always give a -1 value to the production line where we want the route to arrive. After setting all the parameters of the Solver, the batch optimisation can be performed.

Definition of production line pairs

In the next step, we use the shortest paths to form pairs of production lines, which are considered as one production line, thus reducing the number of production lines to be taken into consideration.

The pairs of production lines are formed based on the common edges. The production lines that have significant number of common edges are put into a production line pair. This analysis is made for each potential production line pairs.

The common edges can be defined using the the binary values, if the shortest route to both production lines for a given route section is 1, then there is a common edge. Such matches are counted, added together and the total number of possible common edges for all possible pairs of production lines is obtained. However, the finding of a production line pair depends not only on the number of common edges, but also on the distance between the shortest routers to the two production lines. This is necessary because common edges far away from the warehouse have a significantly higher number of common edges than those close to the warehouse, so that taking the distance into account, a much more realistic value is obtained by using it as a ratio.

```
Dim x As Integer, i As Integer, j As Integer
Dim string1 As String, string2 As String


For x = 0 To 25
For i = 4 To 108
For j = 5 To 29

string1 = Cells(2, 4 + x).Value
string2 = Cells(2, j + x).Value


If Cells(i, 4 + x).Value = 1 Then
    If Cells(i, j + x).Value = 1 Then
        Cells(i, j + 30 + 30 * x).Value = 1
    End If
End If

Cells(110, j + 30 + 30 * x).Value = WorksheetFunction.CountIf(Range(Cells(3, j + 30 + 30 * x), Cells(190, j + 30 + 30 * x)), 1)
Cells(111, j + 30 + 30 * x).Value = string1 & "-" & string2

Next j
Next i
Next x
```

Figure 3 – Algorithm to analyse the identity of edges

Definition of production line groups

The next step of the optimization is to use the ratio defined in the previous section to determine the two groups of production line pairs for which the milkrun routes will be optimized separately. Starting with the highest ratio, the common edges are connected in descending order until two large groups of lines are formed.

6. RESULTS

Once we have the two groups of production lines for which we want to optimize the routes, we perform the minimization. The settings of the Solver are exactly the same as for the optimization for one milkrun route. The most important parameters of the optimal route are the followings: length of the routes are 95.1 and 117.4 distance unit, required time is 285.3 and 352.2 seconds, idle time is 140 and 120 seconds and total required time is 425.3 and 472.2 seconds.

The results obtained meet the predefined time-related constraints for the Milkrun trolleys and the times required to cover the route are almost the same, so the optimisation is considered complete. In case the obtained time results do not meet the constraints, the method described for the optimization of multiple milkrun trolleys should be repeated by increasing the number of milkrun trolleys.

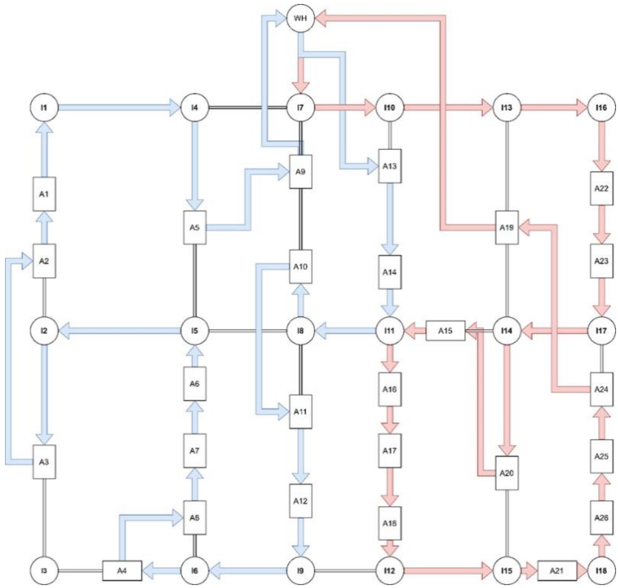

Figure 4 – The optimised milkrun routes in the manufacturing plant

7. SUMMARY

Today, the automotive industry is increasingly influenced by customers' demands. Lead time is a significant part of the processes performing manufacturing. In an automotive supplier's production logistics system, there are many methods to achieve a flexible and well-functioning material flow. One such system is the milkrun system, which implements material flow by creating route among manufacturing objects. The topic of this paper was the optimization of Milkrun systems, where we have presented a methodology to optimize single or multiple milkrun paths. The process has been illustrated through a numerical example. Potential future research direction is the application the mentioned milkrun optimisation method for transportation problems, especially in the case of first-mile problems regarding intermediate storage networks [17], and it is also possible to take the potential of Industry 4.0 technologies [18] for the real-time routing into consideration.

ACKNOWLEDGEMENT

The described article was carried out as part of the NTP-SZKOLL-20-0022 National Talent Program of the Ministry of Human Capacities. The research is supported by the ÚNKP-21-1. New National Excellence Program of the Ministry for Innovation and Technology from the source of the National Research, Development and Innovation Fund.

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ОПТИМІЗАЦІЯ МАРШРУТІВ MILKRUN У ВИРОБНИЧИХ СИСТЕМАХ АВТОМОБІЛЬНОЇ ПРОМИСЛОВОСТІ

Анотація. *Внутрішньозаводські поставки мають великий вплив на продуктивність виробничих операцій, оскільки логістичні операції, що пов'язані з виробництвом впливають на ефективність виробництва. Існують різні рішення для внутрішньозаводського постачання. В автомобільній промисловості широко використовуються рішення Milkrun та Water Spider. В рамках цієї статті автори описують оптимізацію маршрутів Milkrun на заводі постачальника автомобілів. Описана методологія спрощує завдання для задач з одним і декількома Milkrun, і рішення демонструється методологією на основі Excel Solver. Процес оптимізації та його здійсненність продемонстровано на прикладі. Коли ми маємо дві групи виробничих ліній, для яких ми хочемо оптимізувати маршрути, ми виконуємо мінімізацію. Налаштування «розв'язувача» такі самі, як і для оптимізації для одного маршруту Milkrun. Найбільш важливими параметрами оптимального маршруту є наступні: протяжність маршрутів 95,1 та 117,4 одиниці відстані, необхідний час 285,3 та 352,2 секунди, час простою 140 та 120 секунд та загальний необхідний час 425,3 та 472,2 секунди. Отримані результати відповідають визначеним тимчасовим обмеженням для візків Milkrun, а час, необхідний для проходження маршруту, практично однаковий, тому оптимізація вважається завершеною. У випадку, якщо отримані часові результати не відповідають обмеженням, слід повторити метод, описаний для оптимізації кількох візків для Milkrun, збільшивши кількість візків для Milkrun. Потенційним майбутнім напрямком досліджень є застосування згаданого методу оптимізації Milkrun пробігу для транспортних завдань, особливо у разі проблем першої милі щодо мереж проміжного зберігання, а також можливе використання потенціалу технологій Індустрії 4.0 для вирішення транспортних завдань. враховувати маршрутизацію у реальному часі.*

Ключові слова: *Milkrun; оптимізація; логістичний процес; автомобільна промисловість.*