Summer 6-23-2023

Optimization of Cargo Handling Equipment at the Airport

David Sourek
University of Pardubice, David.Sourek@upce.cz

Optimization of Cargo Handling Equipment at the Airport

David Šourek
Faculty of Transport Engineering
University of Pardubice
Pardubice, Czech Republic
David.Sourek@upce.cz

***Abstract*— Delaying an aircraft during ground handling costs the airline a lot of money. In critical situations, it is even possible that some flights have to be canceled due to delays. It is therefore the endeavor of all personnel involved in ground operations that they proceed without delay. This paper shows what methods can be used to optimize the required number of handling equipment and what can affect its number.**

Keywords—ground handling, optimization, airport, cargo handling equipment.

I. Introduction

The number of transported passengers and the volume of transported goods grew continuously in air transport until 2020. Due to the global pandemic, there was a decrease in passenger air transport, which has not been recorded in history so far. However, this situation did not apply to air freight, which even increased slightly compared to previous years. By 2020, many of the world's major airports (and not only those) were heavily used, and in many cases their capacity was almost or completely exhausted in terms of the number of arriving and departing aircraft and the size of aprons. To address this situation, consideration was given to expanding the airport with another runway or build a new airport terminal with another apron. However, in most cases, this solution to capacity problems cannot be used for spatial and other reasons. The only possible solution was often to find the places and activities that most affect the time the aircraft stay (turnaround) at the airport.

Thanks to the rapid decline in the number of flights in passenger transport, airport capacity problems have been solved for at least a few years [1]. It is not yet clear how long it will take to achieve performance comparable to the year 2019. To reduce operating costs, many airlines will want to get rid of unused aircrafts. For the one that will remain in operation, the airline will focus mainly on its efficient use, e.g. on the aircraft to spend the shortest possible time on the ground. Similar considerations regarding the use of technical equipment will be addressed by handling companies that take care of the technical handling of aircraft. They, too, now have an abundance of handling equipment, which is gradually becoming obsolete and remains unused. They will therefore look for ways to determine its optimal number, assuming different lengths of time needed to regain performance as before 2020.

In order to determine the overall minimum time required for an aircraft stay at the airport, it is necessary to know in detail all the processes that must necessarily take place before its next trip. These processes can be divided into the following groups:

- Airplane movement at the airport;
- Passengers boarding and disembarking, including check-in and transfer to / from aircraft;
- Ensuring airworthiness (preflight inspection, refueling, etc.);
- Loading and unloading of luggage and goods.

From the material handling point of view, the most interesting group of activities is the group focused on loading and unloading of luggage and goods. Other activities are also very important and must be given due attention, but they are outside the scope of this paper.

Among the above-mentioned technological processes taking place at the airport, loading and unloading of luggage and goods into and out of aircraft may seem as a very easy task. Unfortunately, the opposite is true. The whole process of aircraft loading and unloading consists of many partial activities, which must be continuously connected. Without their coordination, there will be downtime and delays, because some subsequent activities cannot start before other preceding activities are finished.

The process of preparation for loading, but also the loading and unloading of aircraft, cannot be done without the use of special handling equipment. This equipment includes mobile belt conveyors, tractors with cage or platform trailers and scissor lifts adapted to handle aircraft containers and pallets (Fig. 1). Preparation for loading takes place in part in the baggage sorting facility, where passengers' baggage is collected according to individual flights. Depending on the type of aircraft used and at the discretion of the airline, luggage is loaded either directly on trolleys or in air containers (ULD). The second part of the preparation takes place simultaneously in the cargo terminal (if the airport has one) or in the reserved part of the baggage sorting facility. The goods that will be loaded into the passenger aircraft as a supplement to maximize its carrying capacity and increase the airline's income are prepared in the cargo terminal. Of course, the goods can also be prepared for transportation by cargo aircraft, but the preparation process is no different from the previous one. The goods are, according to their character, loaded into air containers or on air pallets. At the appropriate

Fig. 1. Ground handling equipment (from left: belt conveyor, scissor lift, tractor with cages)

moment, the goods (and also luggage from the sorting center) are transported by means of a tractor and trolleys to the aircraft, where loading is carried out using special handling technology. Aircrafts unloading, which of course precedes their loading, is carried out using the same handling equipment.

Of course, the goods can also be prepared for transportation by cargo aircraft, but the preparation process is no different from the previous one. The goods are, according to their character, loaded into air containers or on air pallets. At the appropriate moment, the goods (and also luggage from the sorting center) are transported by means of a tractor and trolleys to the aircraft, where loading is carried out using special handling technology. Aircrafts unloading, which of course precedes their loading, is carried out using the same handling equipment.

The number of individual types of handling equipment is essential to speed up the process of loading and unloading aircraft and thereby minimizing the duration of the aircraft's stay at the airport. For many reasons, however, it is not possible for each aircraft parking position to have a complete set of necessary handling equipment. This handling equipment is shared throughout the airport during loading and unloading of aircraft and moves as needed to individual aircraft. The abundance of handling equipment results in a low degree of utilization, as well as higher costs for acquisition, maintenance and renewal. On the other hand, its lack can cause aircraft delays and thus financial losses for airlines and airports. It is therefore very important to correctly determine the amount of handling equipment needed.

II. Literature Review and Problem Background

In the literature, the problem of determining the optimal number of handling equipment at the airport is not paid much attention, although its solution may be crucial to shorten the time which spent aircraft at the airport and to increase the dynamic apron capacity at the airport (it is not the main problem nowadays for passenger transport). Some authors (e.g. [2] or [3]) focus on scheduling staff shifts at airport cargo terminals. This issue is in some features similar to the problem of determining the minimum number of handling equipment. The main difference is that the commitment of workers is much more flexible due to the possibility of different working hours. The costs of employees thus arise for the most part only according to the number of hours worked. This is not possible for handling equipment because it requires an initial investment that does not depend on its later use. Other authors (e.g. [4]) solve the assignment of aircraft to the gates of the cargo terminal for unloading according to the final destination of goods so that the flow of goods through the terminal is optimal. The similarity is in the solution of the assignment problem, but with very different parameters. The literature review on air cargo operations ([5], [6]) lists other issues that are addressed in the context of the air cargo. For example, fleet routing and flight scheduling, aircraft balancing, or aircraft loading (how to load the maximum number of containers into aircraft). None of the authors deals with the question of determining the optimal number of individual types of handling equipment for loading and unloading luggage and goods to and from aircraft.

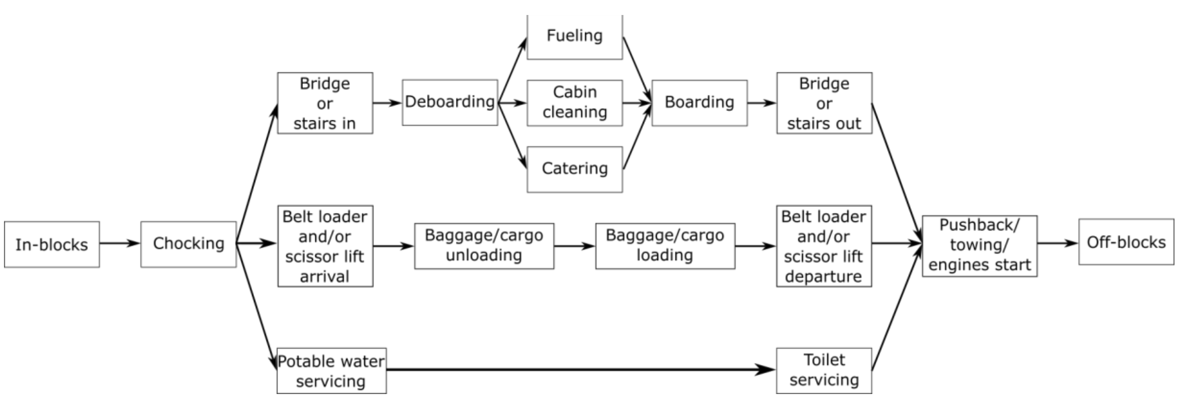

Fig. 2. Ground handling processes

A. *Ground handling processes*

In most cases, ground handling is divided into two parts. One part is made up of processes that take place inside the terminal. These include passenger check-in (not part of this article) and baggage/cargo preparation for loading onto the aircraft. The start of these processes is determined by the time when passenger check-in is to begin (typically two hours before the aircraft's departure). These processes usually start independently of the current arrival time of the aircraft. The second part of the processes takes place on the apron (ramp). The start of these processes is influenced by the actual arrival of the aircraft at the airport and its arrival at the gate or at the designated stand. The moment the aircraft stops at a designated place is referred to as In-blocks.

After stopping the aircraft, the engines must be switched off and the aircraft must be secured against further movement. This process is referred to as chocking. This is followed by marking the outline of the aircraft using cones so that it is not damaged during handling in its vicinity. The aircraft is also connected to an external power source and, if necessary, to an external air conditioning unit. All these activities are ensured by handling staff who are already waiting for the arrival of the aircraft at the given stand.

The other activities related to the ground handling of the aircraft at the airport follow. Some activities can take place simultaneously with others, others can only start at the moment when another (preceding) activity ends. The continuity or parallelism of these processes is shown in Fig. 2. An aero bridge is pushed to the plane for passengers to exit, or stairs are added to it. After the exit of passengers is completed, the cleaning of the passenger cabin, the disposal of garbage produced during the flight and the replenishment of new refreshments for the next flight can begin. If the plane stays at the airport overnight, fresh refreshments will only be loaded in the morning before departure. Simultaneously with these activities, it is also possible to start refueling for the next flight (if the aircraft does not yet have enough fuel from the departure airport). For safety reasons, refueling is usually done without passengers on board. To reduce turnaround time, it is possible to complete refueling when passengers board. In this case, however, it is necessary to request the assistance of firefighters in accordance with safety regulations. At any time during the performance of these activities, it is possible to start topping up potable water and emptying the waste water tank. However, these two activities cannot take place at the same time. First, the potable water filling must be completed and only then can the waste tanks be emptied.

The last group of activities that can be performed simultaneously with the above mentioned is the unloading and loading of luggage and/or cargo. These activities can begin immediately after the aircraft is chocked and are not dependent on activities related to passengers or to the passenger cabin. A belt loader and/or scissor lift must be attached to the aircraft to begin unloading. The use of a specific type of handling equipment depends on whether the passengers' baggage is transported here as bulk or if air containers (ULD) are used. A belt conveyor is used to unload loose baggage, which is used to get the baggage from the cargo hold of the plane to the attached trolley. A minimum of two workers are required for this process. One is inside the plane putting luggage on the conveyor belt. The other is on the ramp taking luggage from the conveyor belt and transferring it to caged carts. More workers can be used to speed up the process. On some flights with loose baggage, additional cargo (referred to as payload cargo) may be transported in another cargo compartment, which is stored in air containers or on air pallets. In such a case, it is necessary for the aircraft to have a scissor lift available (in addition to the belt conveyor) that will allow the handling of air containers or pallets. Some airlines prefer to transport luggage in air containers. In this case, there is no need for a conveyor belt and only a scissor lift (one or more) is sufficient to unload luggage and cargo from the aircraft.

All unloaded cargo and luggage are placed on carts attached to the tractor. In the case of loose baggage, the tow truck does not have to be with the aircraft for the entire unloading period. Empty carts can be easily handled using only human power, so the worker transferring luggage from the belt conveyor to the carts can adjust the position of the empty carts so that they are close to him. When using air containers or pallets, the trucks are usually connected to the tractor during the entire unloading (loading) period, as it is necessary that the position of the loaded truck is adapted to the position of the scissor lift from which the cargo is transferred. Handling a loaded cart using only human power is already very difficult, if not impossible. Depending on the size of the aircraft, individual parts of the cargo area can be unloaded simultaneously or sequentially. Everything depends on the amount of handling equipment that is available at a given moment and on the time, which is necessary for the aircraft to be ready for the next flight.

After unloading is completed, the cargo compartments are inspected and possibly cleaned and loading of baggage and/or cargo can begin. This process is very similar to unloading, with the only difference being that it takes place in the opposite direction, i.e. towards the aircraft. However, there is one more specific feature that can complicate loading. When loading luggage and cargo onto the plane, it is necessary to follow the so-called loading schedule, which determines how heavy cargo can be loaded into a specific part of the cargo space. When using air containers and pallets, the places where the containers and/or pallets are to be loaded are determined in advance. Failure to follow this schedule could result in problems with the balance of the aircraft as well as problems with its controllability. In some cases, it is also necessary to observe the order of loading individual parts of the cargo compartment of the aircraft. If the rear cargo area was loaded first (or the front cargo area was unloaded first), the front part of the aircraft could be significantly lightened and the tail part could move towards the apron and be damaged. Although this is a very extreme case, several such events have already been recorded in practice.

After the completion of all activities related to the aircraft ground handling (be it the boarding of passengers or the loading of luggage and/or other cargo, or other activities not described here), the aircraft is ready for departure. At those airports where the plane is facing the terminal (nose-in stand), it is necessary that, before taxiing to the runway, the plane is pushed away from the terminal into a position that already allows its independent movement forward. If the aircraft was parked on the apron outside the terminal, no pushback is required. Starting the movement of the aircraft in order to take off is referred to as Off-blocks.

From the previous paragraphs, it is clear that many types of handling equipment are needed for the entire ground handling process. If we omit the passenger and passenger cabin processes and focus only on baggage and cargo handling, we find that at least three different types of handling equipment are needed for this activity (tractor with trolleys, belt conveyor, scissor lift). For the purposes of this paper, we are only considering the common type of baggage and cargo handling. The loading and unloading of special cargo aircraft with the possibility of handling equipment entering the fuselage of the aircraft is not paid attention to, as there are not too many such cases compared to other flights and it usually only happens at large international airports with cargo terminals.

As already mentioned at the beginning of the paper, it is important that all the necessary equipment is in the right place at the right time for the smooth progress of ground handling. This would be easily solved if each aircraft stand had its own complete set of necessary handling equipment. Due to the high economic costs that would be associated with this maximalist variant, such an approach is not used anywhere. On the contrary, the minimalist variant would consist of only one piece of handling equipment of each type. This approach would lead to delays that would quickly grow beyond the tolerable limit at airports where multiple aircraft are handled at the same time. It is therefore necessary to search for the optimal number of individual types of handling equipment that the airport will use for ground handling, while observing other optimization criteria. These can be, for example, minimizing the waiting time for the start of ground handling, minimizing ground handling delays or maximizing the use of handling equipment.

B. Overview of common solution methods

Several mathematical methods can be used for optimization, depending on the type of optimization problem and the complexity of the model. Here are some of the most common mathematical methods used for model optimization:

- Linear programming: Linear programming is a method used to optimize linear objective functions subject to linear constraints. This method is widely used for vehicle scheduling problems, including ground handling operations at airports.
- Non-linear programming: Non-linear programming is used for optimizing non-linear objective functions subject to non-linear constraints. This method is useful for solving more complex optimization problems, such as vehicle routing problems and crew scheduling problems.
- Integer programming: Integer programming is used for optimizing objective functions subject to integer constraints. This method is useful for solving discrete optimization problems, such as scheduling problems that involve a limited number of resources.
- Mixed-integer programming: Mixed-integer programming is a combination of linear programming and integer programming. It is used for solving optimization problems that involve both continuous and discrete variables.
- Heuristic methods: Heuristic methods are approximate optimization methods that use rules of thumb or algorithms to find near-optimal solutions to complex optimization problems. Examples of heuristic methods include simulated annealing, genetic algorithms, and tabu search.
- Dynamic programming: Dynamic programming is a method used to solve optimization problems by breaking them down into smaller sub-problems. It is particularly useful for solving optimization problems that involve a large number of variables and constraints.

Overall, the choice of mathematical method for model optimization depends on the specific requirements and constraints of the optimization problem. A combination of different methods may also be used to achieve the best results.

III. Mathematical Formulation of the Problem

To solve the optimization problem, it is also necessary to know the parameters of all processes that influence the optimization criteria. In the case of handling technology, these are the following parameters:

- Type of aircraft
- Amount of baggage/cargo to be handled
- Used handling units
- The time required for handling one handling unit
- The maximum allowable turnaround time of the aircraft according to the flight schedule
- The distance between the place of handling and the current position of the handling equipment

Knowing the type of aircraft is used to determine whether the handling device is compatible with that type. On wide-body aircraft, the cargo floor is much higher above the apron than on smaller aircraft. Not all types of conveyor belts available at the airport must be able to reach the height of the cargo floor. It is also clear from the type of aircraft how much cargo space the aircraft has and whether it makes sense to use more belt conveyors to speed up unloading or loading.

Based on the amount of luggage and cargo, the handling units used and the time required to handle one unit, it is possible to calculate how long the actual unloading and loading process will take. Here, it is assumed that all the necessary handling equipment and the necessary workers are in place. The total time of handling luggage and cargo (during unloading and loading) is marked as t_{ch}.

$$t_{ch} = t_{do} + t_{wp} + t_{id} + t_{un} + t_{wl} + t_{lo} + t_{sc} + t_{ip} + t_{dc} + t_{er}\,[\mathrm{s}] \quad (1)$$

The time t_{ch} consists of the time required to open the cargo door (t_{do}), place the handling equipment in the working position (t_{wp}), the idle time between the start of unloading and the unloading of the first handling unit (t_{id}), the total unloading time including the time for moving the trucks that carry unloaded baggage or cargo (t_{un}), waiting to start loading (t_{wl}), from the total loading time including the time for moving the trolley with baggage/cargo to be loaded (t_{lo}), the times for checking the correctness of the stored cargo (t_{sc}), the times for moving handling equipment to a safe distance from the aircraft (t_{ip}), cargo door closing time (t_{dc}) and total time for accidental breakdowns and unplanned delays (t_{er}). Times t_{un} and t_{lo} are dependent on the number of handling equipment N_{he}, whereby more handling equipment involved in the process, the shorter these times. The maximum amount of handling equipment used for unloading and loading is equal to the number of cargo doors in the aircraft. All sub-times that make up the t_{ch} time are related to one aircraft. If the handling equipment is to be used successively for several aircraft, the handling time is marked as t_{ch}^{i}. Equation (1) then results in the optimization criterion and its limiting conditions.

$$\min_{N_{he}} \sum_i t_{ch}^{i} \quad (2)$$

where *i* is number of served aircrafts.

The maximum allowable turnaround time (t_{tm}) makes it possible to determine at what latest the process of unloading and loading the aircraft must be started, so that the departure is not delayed due to the late completion of baggage or cargo handling. The optimization criterion (2) then holds

$$t_{tm}^{i} \geq t_{ch}^{i}, \forall i \quad (3)$$

The problem of determining the number of necessary handling equipment and its gradual assignment to aircraft can be solved as a vehicle routing problem with time windows and many vehicles. This problem belongs to NP-hard problems due to the non-polynomial complexity of algorithm, which can evaluate all variants of solution. There are several algorithms according to [10, 11, 12] (heuristic, genetic or others but not exact) that can be used for solving the vehicle routing problem with time windows and many vehicles:

- Tabu search: Tabu search is a heuristic algorithm that is useful for solving complex combinatorial optimization problems. It is particularly effective for solving vehicle routing problems with time windows, as it can handle multiple vehicles and constraints.
- Simulated annealing: Simulated annealing is another heuristic algorithm that can be used for solving the vehicle routing problem with time windows and many vehicles. It works by simulating the process of annealing in metallurgy, where a material is slowly cooled to reach a low-energy state. In simulated annealing, the algorithm gradually reduces the probability of accepting worse solutions over time, leading to better quality solutions.
- Genetic algorithms: Genetic algorithms are optimization algorithms inspired by the process of natural selection. They work by generating a population of potential solutions and iteratively applying genetic operators such as crossover and mutation to produce new solutions. Genetic algorithms can handle multiple vehicles and time windows and can be particularly useful for finding near-optimal solutions to complex problems.
- Ant colony optimization: Ant colony optimization is another metaheuristic algorithm that is inspired by the behavior of ants searching for food. In ant colony optimization, the algorithm simulates the behavior of ants laying pheromones to mark good paths and follows the paths with higher pheromone levels. This algorithm can be used to solve the vehicle routing problem with time windows and multiple vehicles.
- Branch and bound: Branch and bound is a method for solving combinatorial optimization problems by recursively breaking down the problem into smaller sub-problems. This algorithm can be particularly useful for solving the vehicle routing problem with time windows and many vehicles, as it can handle complex constraints and dependencies.

All the mentioned methods for solving the vehicle routing problem with time windows can be used in practice. They come into play in the medium-term planning horizon, as the calculation time tends to be relatively long. Because of this, these methods are not suitable for controlled processes in real time, when it is necessary to respond, for example, to delayed arrivals or other deviations from planned operations.

Before using any of the above-mentioned methods to calculate the required amount of ground handling equipment, it is necessary to perform an airport traffic analysis. The output of the analysis will be data on the maximum number of simultaneously handled aircraft at the airport (depending on the flight schedule), what are the turnaround times of individual aircraft and what are the maximum capacities of individual aircraft. Assuming that each of the simultaneously checked-in aircraft would have a complete set of ground handling equipment at its disposal, we will receive the maximum number of these devices. This solution can be considered as the maximum (extreme) possible option, because every other piece of handling equipment would no longer be used (the places for handling equipment on all planes would already be occupied) and would thus remain completely unused. Using one of the above-mentioned methods, this number will then be reduced to an optimal level, subject to compliance with all limiting conditions, especially the aircraft turnaround time.

IV. Conclusion

This paper mentioned methods that can be used to determine the amount of ground handling equipment for unloading and loading aircraft. The entire problem of scheduling handling equipment was simplified by the fact that, along with the assignment of handling equipment for aircraft ground handling, the assignment of workers participating in the mentioned processes was also not addressed. Including these workers in the solution would make the solution situation more complicated. Furthermore, the situation that all luggage or cargo is not brought to the plane at the same time was not considered here either. This is due to the fact that not all passengers start their journey at a given airport. Some have an airport as a transfer point, and their luggage often reaches the baggage sorting facility only after the check-in of passengers has finished and their luggage is already ready for transport to the plane or even already on it.

The solution for assigning handling equipment to flight ground handling is currently combined with Airport Collaborative Decision Making processes. This system enables real-time information sharing among airlines, ground handlers, airport operators, air traffic control, and other stakeholders involved in airport operations. This information includes flight schedules, aircraft turnaround times, resource allocation, and other critical data.

By sharing this information, stakeholders can work together to optimize airport operations, improve the accuracy of flight schedules, and reduce the number of delays and cancellations caused by miscommunications or lack of coordination. The A-CDM system also provides real-time alerts and notifications, allowing stakeholders to respond quickly to changes in airport conditions and minimize disruptions to airport operations.

References

[1] ICAO, "Economic Impacts of COVID-19 on Civil Aviation". [online], https://www.icao.int/sustainability/Pages/Economic-Impacts-of-COVID-19.aspx

[2] A. Rong, M. Grunow, "Shift designs for freight handling personnel at air cargo terminals," in Transportation Research Part E: Logistics and Transportation Review, 45 (5), pp. 725–739, 2009 doi: 10.1016/j.tre.2009.01.005.

[3] S. Yan, C.-H. Chen, C.-K. Chen, "Long-term manpower supply planning for air cargo terminals," in Journal of Air Transport Management, 12 (4), p. 175–181, 2006. doi: 10.1016/j.jairtraman.2006.01.004 .

[4] L. H. Lee, H. C. Huang, P. Huang, "Flight assignment plan for an air cargo inbound terminal," in Proceedings of the 2010 Winter Simulation Conference, Baltimore, MD, USA. pp. 1872–1881. https://doi.org/10.1109/WSC.2010.5679182

[5] B. Feng, Y. Li, Z.-J. M. Shen, "Air cargo operations: Literature review and comparison with practices," in Transportation Research Part C: Emerging Technologies, 56 , pp. 263–280. 2015 doi: 10.1016/j.trc.2015.03.028

[6] F. Brandt, S. Nickel, "The air cargo load planning problem - a consolidated problem definition and literature review on related problems," European Journal of Operational Research 275 (2019) pp. 399–410. https://doi.org/10.1016/j.ejor.2018.07.013

[7] S. Padrón, D. Guimarans, J. J. Ramos, S. Salma Fitouri-Trabelsi, "A bi-objective approach for scheduling ground-handling vehicles in airports," in Computers & Operations Research, 71, pp. 34 – 53, 2016, https://doi.org/10.1016/j.cor.2015.12.010

[8] E. Popova, "Staff Scheduling in Ground Handling Company," master thesis at Universitat Autonoma de Barcelona, 2015

[9] E. C. López, F. Marmier and F. Fontanili, "Bus Fleet Size Dimensioning In an International Airport Using Discrete Event Simulation," 2019 Winter Simulation Conference (WSC), National Harbor, MD, USA, 2019, pp. 464-475, doi: 10.1109/WSC40007.2019.9004878.

[10] G. Laporte, "The vehicle routing problem: An overview of exact and approximate algorithms" in European Journal of Operational Research 59 (1992) pp. 345-358. https://doi.org/10.1016/0377-2217(92)90192-C

[11] G. D: Konstantakopoulos, S. P. Gayialis, E. P. Kechagias, "Vehicle routing problem and related algorithms for logistics distribution: a literature review and classification" in Operational Research International Journal 22, pp. 2033–2062 (2022). https://doi.org/10.1007/s12351-020-00600-7

[12] B. Ombuki, B. J. Ross, F. Hanshar, "Multi-Objective Genetic Algorithms for Vehicle Routing Problem with Time Windows" in Applied Intelligence 24, pp. 17–30 (2006). https://doi.org/10.1007/s10489-006-6926-z