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Geographical Information System Modeling for Planning Internal Transportation in a Manufacturing Plant's Outdoor Area

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Abstract: A geographical information system (GIS) is an advanced tool for collecting, managing, and analyzing spatially-referenced data. The contribution of GIS use to process performance indicators can be improved by combining it with multi-criteria decision analysis (MCDA). Combining a GIS and MCDA is, in the scientific literature, rarely discussed for planning an internal transportation system in a manufacturing plant's outdoor area. The purpose of this article is to clarify what mangers can expect from using a combined approach when deciding on a transport fleet and the operational routing of vehicles. Beside the simulation of MCDA, the computer software ArcGIS Pro 3.0.2 with the Network Analyst extension was used for modelling the transportation system in the form of a case study. The article demonstrates the feasibility and effectiveness of GIS and MCDA use and reveals the extent of the challenge of how decision makers could make the most of ArcGIS functionality. The final solution for an internal transportation system in a manufacturing plant's outdoor area includes such a vehicle fleet and the set time windows of orders for transport services, so that there are no violations of time windows and the work is completed within the work shift while minimizing costs, time, and distance. Decision makers can use the program without advanced knowledge of optimization approaches, following a procedure that does not differ much from that of learning to use other business software tools. On the contrary, the listed disadvantages can be summarized as the rigidity of setting detailed boundary conditions for a specific simulation scenario.

Keywords: geographical information system; internal outdoor area transport; decision support system; vehicle fleet; planning

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1. Introduction

Managerial decision dilemmas in the production-business environment are not new [1]. Decision making was originally primarily based on costs. With the ever-faster pace of development, digitalization, industry 4.0, and the emphasis on environmental protection, decision making is becoming complex and requires managers to use simulation and optimization tools.

The article focuses on the organization and conceptualization of the manufacturing plant's outdoor road transports between different production halls placed in a common yard, separated from the public road traffic system, which is a prerequisite of subsequent daily implementation of yard–road transport between facilities of the same company. The literature review reveals several scientific papers on internal transportation inside production halls, workshops, and warehouses between workplaces and departments [2–5]. On the other hand, many scientific papers deal with route planning and optimization of transportation using public road traffic routes [6–8] and last-mile delivery [9,10]. However, the literature review reveals a lack of scientific research on the open/outdoor area yard transport between facilities of the same company. Under the term "outdoor area", we consider an area that stretches inside the manufacturing company's complex but outside the production and warehousing halls and buildings. Since the company owns these areas privately, they are not intended for public road traffic.

The challenges decision makers face in the aforementioned focus area are to properly configure the fleet of vehicles and the associated team of drivers or to think about how to create fewer costs with the existing fleet of vehicles, use less energy, or increase environmental friendliness. In the scientific literature, these challenges are most closely answered in articles with the key phrase Vehicle Routing Problem (VRP). This problem was defined by Dantzig and Ramser [11] and tends to minimize the total transportation cost and seeks a route to deliver orders [12]. Over time, different VRP models and algorithms for the VRP evolved that more frequently incorporate real-life complexities [13]. Braekers with coauthors [13] reported exponential growth in VRP literature of 6% each year. This popularity makes it difficult to keep track of the developments in the field for academics and even more difficult for decision makers. Especially as decision makers want simple tools that do not require programming skills, they do not want to think about algorithms or have to search for the right one. Also, there is a lack of test applications of tools in the field for testing different arrangements of internal transport in the yard of a company, so decision makers cannot even realize how significant the savings are that they could expect with serious consideration of the ways of carrying out internal outdoor-area transport in the yard of their company.

Based on the preliminary research, the article addresses three research questions:

- RQ1: Can ArcGIS software be used for simulating different variants of the implementation of internal transport in a manufacturing plant's outdoor area?
- RQ2: What are the benefits for the decision maker using ArcGIS software to simulate different variants of the implementation of internal transport in a manufacturing plant's outdoor area?
- RQ3: What are the limitations when using ArcGIS Pro software to simulate different variants of implementing internal transport in a manufacturing plant's outdoor area?
- RQ4: What can be expected from integrating an Analytic Hierarchy Process (AHP) into modeling using ArcGIS software?

Six sections outline the research's flow in the article. The results from the literature review are described in Section 2. In Section 3, the test environment and methodology are presented. Results are given in Section 4. The article ends with a discussion in Section 5 and the conclusions in Section 6.

2. Theoretical Background

2.1. Geographical Information System

A geographical information system (GIS) is a form of information system. A fully functional GIS integrates several components and different subsystems [14]. Although practical applications have proven that a GIS is an advanced tool for collecting, managing, and analyzing spatially referenced data, operations research in the scientific literature spreads the opinion that a GIS is a limited tool in the spatial decision-aid domain [14,15].

In transport research, the GIS appeared in the late 1980s [16]. Its contribution to transport research grew during the 1990s [17]. Since the beginning of the 21st century, innovation paths have influenced GISs in transportation research. For example, the situation has flipped from data scarcity to a deluge of sensors and data streams. Further, the policy is forced to move to smart traffic management and a paradigmatic shift to activity-based and micro-scale transport models [17].

In transport research, route selection is often discussed in the literature. A feasible route is defined as one reducing the overall cost of transportation (operating cost, construction cost, minimum separation effects, and environmentally friendly) and increasing efficiency (direct route, shortest travel distance, better accessibility, and mobility options) [18,19]. Solving route selection is characterized by the presence of more than one criteria. The advantage of using a GIS is recognized as enabling the analysis, forecasting, and simulation of real transportation problems [20]. In recent years, there has been an increase in using a GIS for all kinds of transportation planning and modeling [21].

2.2. Vehicle Routing Problem

A VRP tends to minimize the total transportation cost and seeks a route to deliver orders [12]. The classifications of algorithms for the VRP are evident from the recently published literature reviews [13,22]. There are different varieties of VRP [13,23,24], for example, Capacitated Vehicle Routing Problem (CVRP) [25], VRP with time windows (VRPTW) [26], Multi-Depot Vehicle Routing Problem (MDVRP) [27], etc.

In the Network Analyst extension of ArcGIS Pro, integrated VRP is a Vehicle Routing Problem with Time Windows (VRPTW), in which vehicles are constrained to deliver services to customers within certain time intervals. More information about VRPTW is provided in the literature review written by Desrochers with coauthors [28].

The heuristics used in this article in ArcGIS Pro are proprietary and based on a tabu search metaheuristic. However, they have been under continual research and development at Esri [29].

2.3. Multi-Criteria Decision Analysis

A multi-criteria decision analysis (MCDA) is a multi-step process consisting of a set of methods to structure and formalize decision-making processes in a transparent and consistent manner [30]. To use one of many MCDA methods, it is important to define the problem, alternatives, and criteria; these may include different types of costs, environmental-impact indicators, social indicators, energy efficiency, quality, and other specific criteria that are relevant to the problem [31]. MCDAs are used in different fields and are one of the most common decision-making methods. MCDA methods can be classified considering different aspects [32]. For example, a method can be selected based on the type of result [33] while being aware of the possibility of obtaining the same [34,35] or similar results using different methods [36,37] and also the possibility that the results of different methods do not match [31,38–41].

One of the most outstanding MCDA approaches is the Analytic Hierarchy Process (AHP) [42,43], which has its roots in obtaining the relative weights of factors and the total value of each alternative based on these weights.

2.4. GIS–MCDA Research

The last 33 years have evidenced remarkable progress in the quantity and quality of research in integrating GIS and multi-criteria decision analysis (MCDA). The multidisciplinary field of GIS–MCDA has been formed within the GIS community [15]. Scientists and professionals recognize the potential and benefits of joining MCDA to GIS capabilities. Malczewski [15] suggested that GIS–MCDA has generated a large enough body of literature that allows it to be considered an essential subfield of research in GIS science.

Farooq [21] explains the benefits of combining MCDA and GIS as follows. The MCDA allows for assessing criteria and prioritizing alternatives for transport planning. The GIS allows the opportunity to preset the real objects as transport networks on maps and to integrate network characteristics into a data base. The integration of both methods serves to help make decisions for transport planning.

Various MCDM models have been incorporated in GISs in the literature [44], such as the simple additive weighting method, Weighted Product Method, Technique for Order Preference by Similarity to Ideal Solution (TOPSIS), ELECTRE, Analytical Hierarchy Process (AHP), and Fuzzy Analytic Hierarchy Process [45–47].

Pedroso with coauthors [48] revealed that in the transport sector, the AHP method was used for evaluations of public policies, technologies, infrastructure, choice of location for facilities, allocation of resources, and choice of modalities, among others. There is also a high prevalence of the use of the AHP method for multi-criteria analysis for solving problems in the transport sector. Marcharis and Bernardini [49] calculated that the proportion of publications citing the use of the AHP method was 33% among 276 analyzed publications.

The most recognized drawback of the AHP is subjectivity. Preferences differ among decision makers. An AHP will achieve its purpose if implemented in group decision mak-

ing [50], where a compromise amongst the participants can be reached without subjecting the methodology to unnecessary bias. The existing literature shows a high level of study of the applicative use of AHP.

2.5. Research Originality and Contributions

The main contributions of the article are as follows. From the theoretical aspects, this article completes the following:

- Tests the applicability of ArcGIS Pro software for the decision-making process of planning internal transport in a manufacturing plant's outdoor area;
- Proposes steps for the decision-making process of planning internal transport in a manufacturing plant's outdoor area.
- From the industrial perspective, this article completed the following:
- Describes the decision-making process of planning internal transport in a manufacturing plant's outdoor area based on a practical example;
- Defines the advantages of using ArcGIS Pro software for the decision-making process of planning internal transport in a manufacturing plant's outdoor area;
- Defines limitations of using ArcGIS Pro software for the decision-making process of planning internal transport in a manufacturing plant's outdoor area.

This work offers a detailed reference for researchers and practitioners to implement ArcGIS Pro software support for a tactical decision-making processes for planning internal transport in a manufacturing plant's outdoor area in real manufacturing practice.

3. Materials and Methods

3.1. Case Study Background

The case study focuses on a production manufacturing plant's internal transportation in its outdoor areas. The factory produces a variety of retail equipment during two shifts. The morning shift starts at 6:00 a.m. and lasts until 2:00 p.m., and the afternoon shift starts at 2:00 p.m. and lasts until 10:00 p.m. There is no night shift.

Transportation of everything necessary to process the material into finished products is carried out internally in each company facility and externally through the common factory yard. Internal transport is carried out during both shifts. External supply and take-out must, for each day, close at 4:00 p.m. Although in both cases it concerns transport needs within the company, the company's transport service is divided into internal, inside the buildings, and external, in the yard of the company. The two transport methods differ in the type of vehicles used, the period needed for services, the qualifications of the drivers, and the logistics units used.

The production manufacturing plant's outdoor areas are privately owned and stretch inside the company complex but outside the production and warehousing halls and buildings. They are not used for public road traffic. Halls and buildings are interconnected with roads of different categories or color-coded paths on the yard floor. Once routes are established, they are considered permanent or fixed. Various vehicles, which are part of the vehicle fleet, drive along the routes. Once the company configures the vehicle fleet, it is fixed in the medium term, or at least until the end of the depreciation period of the individual vehicle. The choice of vehicles affects their utilization and ability to fulfill orders. However, transport schedules and road-usage regimes can be configured flexibly, contributing to higher utilization of vehicles at the operational level or for the daily execution of orders.

The article is intended to decide on the configuration of the internal transport system for the manufacturing plant's yard before it is put into use. This phase is called planning the internal transport system in the manufacturing plant's yard, which is carried out once and fixes the configuration of the vehicle fleet and road traffic regimes. When the planned system is operational, planners can still change driving schedules, drivers' working hours, and break times, but they cannot easily add and remove vehicles. The initial phase of planning an outdoor internal transport system is important in the phase before the purchase

of vehicles for the vehicle fleet and should be based on playing with different configurations of the vehicle fleet in order to achieve the realization of orders and, at the same time, make the best possible use of the fleet and drivers.

The most important input data for planning the outdoor internal transportation system are the content of orders received from the production halls and warehouses within the production complex, which require the movement of logistics units between halls. The so-called internal transportation orders define the characteristics of the logistics units in internal transport (dimensions, mass, special requirements), the start and destination locations, and the estimated time window for the movement. For decision makers, the main goal of planning is to establish such a system in which all orders will be realized within the required time windows. A delay can stop a company's primary production process and thus market supply. The percentage of fulfilled orders is the most important key performance indicator from which decision makers evaluate the quality of the simulation scenario. Other key performance indicators are costs, driver occupancy, vehicle occupancy, and fuel consumption. Parameters such as wait time and distance traveled are also important, with the latter being more from an explanatory point of view.

The input data are also the properties of the transport routes (permitted speed, course within the geographical space, permitted direction of travel, mass limit) in the manufacturing plant's yard. In most cases, adding new routes during the planning phase is impossible, but the traffic regime can be conditionally changed.

3.2. Production System Layout and Processes

The privately owned manufacturing plant complex includes two production halls (Production Hall I (PH I) and Production Hall II (PH II)), a tool shop (TS), a warehouse for materials (WM), a warehouse for finished products (WFP), and a wasteyard (Figure 1). A tool shop (TS) is a production hall where tools used in a production process are made or repaired. A wasteyard (WY) is an asphalted area where larger roll containers are placed for separate waste collection. The listed facilities are connected via private roads. The system of private roads is connected to the public road network with a connecting road. Private roads differ regarding maximum driving speed and permitted driving direction (Figure 1). Maximum driving speed is 5 or 40 km/h. On some roads, it is permissible to drive in both directions and on others only in one direction. In the case study, all vehicles drive on all routes at the maximum permitted speed and only in the permitted direction. The assumption that vehicles drive at the maximum allowed speed makes sense given that they can easily reach speeds of up to 110 km/h. The roads' widths and curve radii allow vans, trucks, and trailers to circulate on all routes.

Traffic on the private road network is dictated by the needs of the production processes carried out in PH I and PH II. Materials and tools that are ready to work must be brought to the production halls, while finished products, used, or unnecessary tools and waste are taken away. All materials are stored in the WM, and all finished products await shipment to customers in the WFP. In PH I and PH II, different products are produced. As a result, the two production halls need different materials for their work which are stored in the WM. PH I and PH II's waste is transported to WY. All tools are stored and prepared for work in the TS.

Each facility has its intralogistics system inside the building that runs the material flow within each facility and is self-sufficient. Because PH I and PH II need WM, WFP, TS, and WY services, the company must provide transport between the facilities using the so-called outdoor transportation system, which is the subject of modeling in this article.

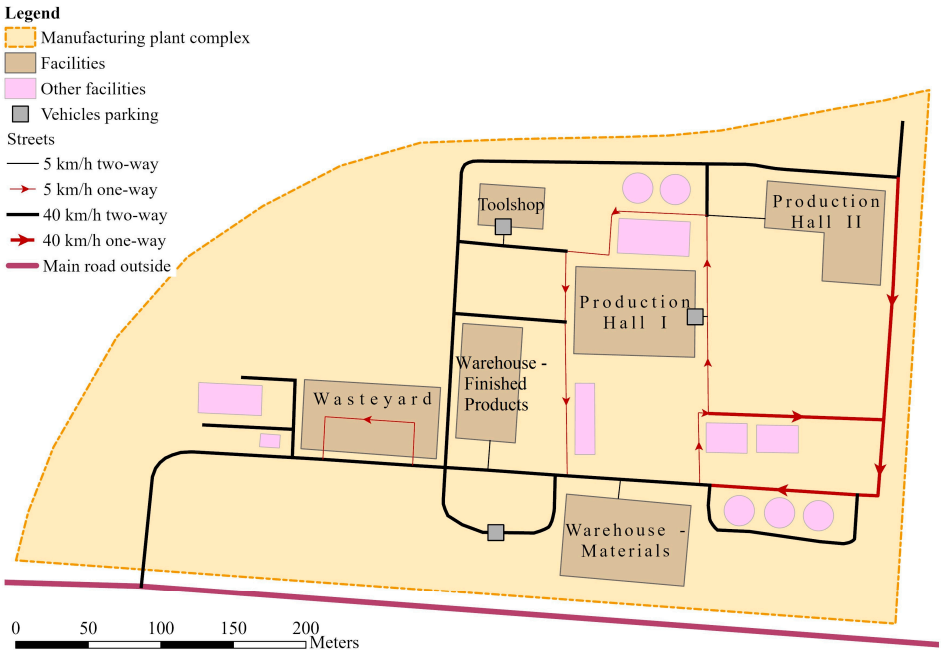


Figure 1. Manufacturing-plant-complex layout.

The starting points for planning the outdoor transportation system are the orders from the production halls (PH I and PH II) to deliver materials and tools and to send out final products and waste. Orders are placed by two production facilities, separately. Each order defines what is needed, and the time window for the transportation service is to be provided. Each order presented in Table 1 puts together different or the same items that have a common initial and final destination and are expected to be delivered in the same time window. Each item is always required to be at least in the quantity of one pallet. Time windows are defined in collaboration with the WM, WFP, and TS. The time window begins when one or several logistics units are ready for transportation and ends with the last moment when one or several logistics units would still be delivered in time. Suppose the vehicle of the outdoor transport system is late and performs the service out of the given time window. In that case, the production process stops, increasing costs and reducing the manufacturer's reputation.

Table 1. List of orders for one working day.

ID	Orders	The Number of Pallets [Piece]	Required Time Window	
			Delivery Start Time	Delivery End Time
1	Finished Products (from PH I to WFP)	4	06:00:00	08:00:00
2	Finished Products (from PH I to WFP)	3	07:00:00	11:00:00
3	Finished Products (from PH I to WFP)	4	08:00:00	11:00:00
4	Finished Products (from PH I to WFP)	4	09:00:00	11:00:00
5	Finished Products (from PH I to WFP)	2	10:00:00	11:00:00
6	Finished Products (from PH I to WFP)	3	11:00:00	13:25:00
7	Finished Products (from PH I to WFP)	4	12:00:00	13:25:00
8	Finished Products (from PH I to WFP)	4	12:45:00	13:25:00

Table 1. *Cont.*

ID	Orders	The Number of Pallets [Piece]	Required Time Window	
			Delivery Start Time	Delivery End Time
9	Finished Products (from PH II to WFP)	8	06:00:00	08:00:00
10	Finished Products (from PH II to WFP)	6	07:00:00	11:00:00
11	Finished Products (from PH II to WFP)	8	08:00:00	11:00:00
12	Finished Products (from PH II to WFP)	8	09:00:00	11:00:00
13	Finished Products (from PH II to WFP)	4	10:00:00	11:00:00
14	Finished Products (from PH II to WFP)	6	11:00:00	13:25:00
15	Finished Products (from PH II to WFP)	8	12:00:00	13:25:00
16	Finished Products (from PH II to WFP)	8	12:45:00	13:25:00
17	Materials (from WM to PH I)	8	06:30:00	07:30:00
18	Materials (from WM to PH I)	14	08:00:00	09:00:00
19	Materials (from WM to PH I)	8	10:00:00	11:00:00
20	Materials (from WM to PH I)	14	11:00:00	12:00:00
21	Materials (from WM to PH II)	10	06:00:00	07:00:00
22	Materials (from WM to PH II)	9	07:00:00	08:00:00
23	Materials (from WM to PH II)	10	08:30:00	09:30:00
24	Materials (from WM to PH II)	9	09:30:00	10:30:00
25	Materials (from WM to PH II)	10	11:45:00	12:30:00
26	Materials (from WM to PH II)	9	12:30:00	13:00:00
27	Tools (from TS to PH I)	3	06:30:00	07:30:00
28	Tools (from TS to PH II)	2	06:30:00	07:30:00
29	Tools (from PH II to TS)	1	09:30:00	11:00:00
30	Tools (from PH II to TS)	2	12:00:00	13:15:00
31	Tools (from PH I to TS)	1	11:00:00	12:30:00
32	Tools (from PH I to TS)	3	12:00:00	13:15:00
33	Waste (from PH II to Wasteyard)	1	07:00:00	08:00:00
34	Waste (from PH II to Wasteyard)	1	11:00:00	12:00:00
35	Waste (from PH II to Wasteyard)	1	12:30:00	13:05:00
36	Waste (from PH I to Wasteyard)	1	07:00:00	08:00:00
37	Waste (from PH I to Wasteyard)	1	11:00:00	12:00:00
38	Waste (from PH I to Wasteyard)	1	12:30:00	13:05:00
39	Empty box pallet (from WY to PH I)	1	07:10:00	08:10:00

Table 1. *Cont.*

ID	Orders	The Number of Pallets [Piece]	Required Time Window	
			Delivery Start Time	Delivery End Time
40	Empty box pallet (from WY to PH I)	1	11:10:00	12:10:00
41	Empty box pallet (from WY to PH I)	1	12:40:00	13:15:00
42	Empty box pallet (from WY to PH II)	1	07:10:00	08:10:00
43	Empty box pallet (from WY to PH II)	1	11:10:00	12:10:00
44	Empty box pallet (from WY to PH II)	1	12:40:00	13:15:00

3.3. Transportation Network Model Creation

The computer software ArcGIS Pro 3.0.2 with the Network Analyst extension was used for modeling the internal transport in the manufacturing plant's outdoor area. The VRP method using ArcGIS Pro is clearly explained in ArcGIS Pro Help [29], and the publicly published data are summarized below.

The VRP is a superset of the traveling salesman problem (TSP). The TSP is a combinatorial problem, meaning there is no straightforward way to find the best sequence. Heuristics are used to find good solutions to these types of problems in a short amount of time. The TSP implementation in Network Analyst also handles time windows of the stops; that is, it finds the optimal sequence to visit the stops with the minimum amount of lateness. The traveling salesman solver starts by generating an origin–destination cost matrix between all the stops to be sequenced and uses a tabu search-based algorithm to find the best sequence for visiting the stops.

In the TSP, one set of stops is sequenced in an optimal fashion. In the VRP, a set of orders must be assigned to a set of routes or vehicles such that the overall path cost is minimized. It also must honor real-world constraints including vehicle capacities, delivery time windows, and driver specialties. The VRP produces a solution that honors these constraints while minimizing the objective function composed of operating costs and user preferences, such as the importance of meeting time windows. The VRP solver starts by generating an origin–destination matrix of the shortest-path costs between all order and depot locations along the network. Using this cost matrix, it constructs an initial solution by inserting the orders one at a time onto the most appropriate route. The initial solution is then improved by resequencing the orders on each route, as well as moving orders from one route to another, and exchanging orders between routes.

For the requirements of the present case study, a visualization map and a network dataset were modeled in the Slovenia 1996, Slovene National Grid projected coordinate system [44].

VRP network analysis was based on a network dataset, representing a transportation network model. The network dataset was created from simple source features (lines and points) and stores the connectivity between them. In the model, lines represent edges over which agents travel. Points represent junctions, which connect edges and facilitate navigation from one edge to another. In reality, the model represents roads over which loaded and unloaded vehicles travel.

A VRP solver in ArcGIS Pro is a variant of the basic VRP, namely a Vehicle Routing Problem with Time Windows (VRPTW), where vehicles are constrained to deliver services to customers within certain time intervals. The VRP solver starts by generating an origin–destination matrix of the shortest-path costs between all order and depot locations along the network. Using this cost matrix, it constructs an initial solution by inserting the orders one at a time onto the most appropriate route. The initial solution is then improved through resequencing the orders on each route, as well as moving orders from one route to

another, and exchanging orders between routes. The heuristics are based on a tabu search metaheuristic [29].

In the created VRP layer, several network analysis classes were applied, namely, orders, depots, routes/vehicles, breaks, route specialties, order specialties, order pairs, and depot visits. Depots are locations where vehicles start and end their shift, including start and end service time. Route and order specialties were used to assign specific orders to certain vehicles. An order-pairs function was used to pair delivery and pickup orders to reduce the number of trips. For example, a logistics unit (pallet) must be picked up in the warehouse and delivered to the production hall. These related stops were assigned to the same vehicle. Some situations required two pairs of orders. Such an example was demonstrated when carrying a full box pallet from the production hall to the wasteyard, which was one pair, and then carrying an empty box pallet back from the wasteyard to the production hall, which was another pair.

3.4. AHP Methodology

The case study has been solved in accordance with the AHP methodology. In the decision-making process, the decision-making roles were clearly defined. The chief executive officer (CEO) of the production manufacturing plant was the main decision maker, supported by the head of the logistic department and the head of the production department. It is a method of organization that is often present within companies and follows a hierarchically organized decision-making structure. In this case, the head of the logistic department and the head of the production department represent the interests of their respective departments, while the CEO of the company represents the interests of the company as a whole. The authors of the article assisted them operationally in the roles of analysts. The analysts constructed the model in ArcGIS Pro, simulated different scenarios, and suggested decision tools to solve the problems.

Considering [41,42,51–53], the solution procedure has been divided into the following steps:

- Recognition of the category of the decision problem (ranking problem);
- Definition of the set of variants (direct definition of the available vehicles);
- Construction of the consistent family of criteria (three criteria: total cost, total traveled distance, and total order-fulfilment time);
- Modeling and aggregation of the decision maker's preferences (weights and thresholds);
- Solving the decision problem (defining vehicles and the selection of one transport scenario).

The exclusion condition is the total violation time (TV_n) which needs to be zero. The total violation time is a sum of all violation times during the order-fulfilment process. The route may arrive at an order before the beginning of one of that order's time windows, in which case there is a wait time at that order. For an order with soft time windows, the route may also arrive at the order after the end of one of the time windows, in which case there is a violation time at that order.

Total order-fulfilment time or "Total time" or "total route duration" includes travel times as well as service and wait times at orders, depots, and breaks. Total traveled distance includes traveled distance for orders' fulfilment as well for services and breaks. Total cost includes the cost per unit time (driver and vehicle) and cost per unit distance (average mileage).

3.5. Simulation Scenarios

In total, 49 different simulation scenarios were performed in ArcGIS Pro by manually setting the company's transportation network, loading and unloading locations, transport-fleet composition, vehicles' characteristics, time windows based on the list of orders, and rules for allocating orders to vehicles (Figure 2).

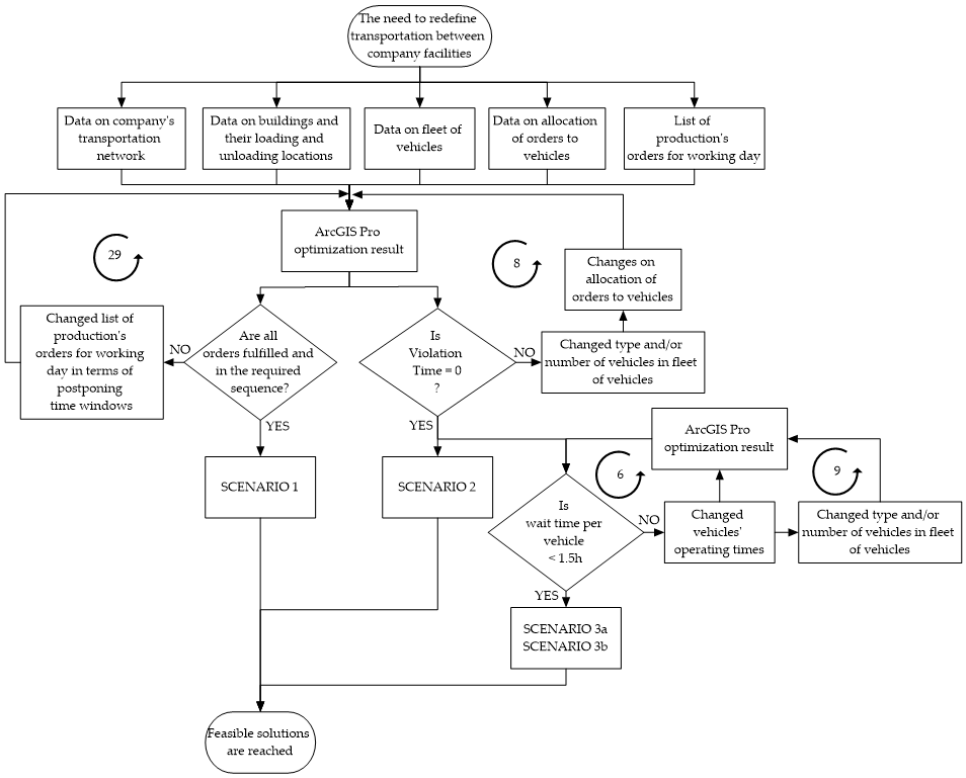


Figure 2. The procedure for determining feasible process scenarios.

The process of determining feasible process scenarios was initially based on the existing transport system. It would be most advantageous for the company if the planned increased production volume could be logistically supported with the existing transport fleet consisting of a forklift, a van, and a truck. After the first simulation in ArcGIS Pro, it was clear that the existing fleet could not supply the production within the required quantities, time windows, and sequence of deliveries.

In order to maintain the existing fleet, the production manager corrected the list of orders 29 times based on changes in the sequence of technological operations in the production plan. Each changed list of orders triggered a new ArcGIS Pro simulation and inquiry if all the required orders were fulfilled and performed in the required sequence. The 29th version of the production's list of orders was the one that allowed the existing fleet to deliver all orders in the required sequence, but with a noticeable violation time (delivery outside the required time window). The resulting scenario is called Scenario 1, the first feasible scenario, the advantage of which is that it does not require investments in changing the composition of the vehicle fleet. It offers to production a slightly lower-quality service in terms of the punctuality of deliveries, but it enables it to produce all expected quantities of the products.

After obtaining Scenario 1, the production department was not completely satisfied due to the observed violation times. Scenario 1 enables 100% production of all products, but with clearly expressed delays. This would certainly jeopardize the achievement of the planned realization of the production process. The decision-making team (including the head of the logistics department, the head of the production department, the CEO of the company, and the analyst) returned to the originally requested list of orders (Table 1). The range of transport vehicles on the market was reviewed, and suitable vehicles that the company could afford to buy were selected. The analyst simulated eight possible scenarios based on changes in the composition of the current vehicle fleet. The eighth scenario turned out to be a feasible solution and was called Scenario 2. It features a zero violation time, which means that all orders are delivered within the required time windows. The quality of

service is impeccable for production in terms of quantities, delivery times, and sequencing, but it requires investment in new transport vehicles.

After obtaining Scenario 2, the logistics department was not completely satisfied. The logistics department recognized that a large amount of waiting time was a problem. Although the drivers would deliver all orders within the required time windows and in the required sequence, drivers often wait for the next order between deliveries. The implementation of the logistics services of Scenario 2 does not follow the practice of rational management.

After discussing Scenario 2, the decision-making team returned, again, to the originally requested list of orders (Table 1). In collaboration with the decision-making team, the analyst simulated six possible scenarios based on changes in vehicles' operating times and nine scenarios based on changes in vehicles' operating times and type and/or number of vehicles in the transport fleet. The goal was to find a solution where the waiting time would not exceed 1.5 h or 20% of the driver's working time within an eight-hour shift. Scenario 3a and scenario 3b were obtained, representing two feasible solutions. However, it was not clear which of the two scenarios represents a more favorable solution for the company.

Four feasible scenarios were designed for analysis and comparison, namely Scenario 1, Scenario 2, Scenario 3a, and Scenario 3b. For all scenarios, the shift starts at 6:00 a.m. Scenarios differentiate in the following ways (Tables 2–5):

- Types of vehicles (truck, truck with a trailer, van, and forklift). Variables depending on the type of vehicle are as follows:
  - Designated depot, where the vehicle starts and ends its tasks and spends a certain amount of service time;
  - Capacity, determined by the maximum number of transportation units the vehicle can transport;
  - Costs, defined per time unit (minute) and distance unit (kilometer).
- Total vehicle operating time (full-time or part-time).

Characteristics of individual vehicles are as follows:

- Forklift:
  - Capacity_1: max 1 pallet 1.2 × 1.0 × 1.0 m;
  - Capacity_2: max 1.2 m^3;
  - Capacity_3: max load 1000 kg;
  - Cost per unit time: 12.5 EUR/h, taking into account the average cost of the monthly rent of a forklift and the cost of the average salary of a forklift driver in Slovenia;
  - Cost per unit distance: 0.016 EUR/km, electric drive, electricity consumption 9 kWh/h;
  - Start depo service time: 5 min;
  - End depo service time: 10 min.
- Van:
  - Capacity_1: max 2 pallets 1.2 × 1.0 × 1.0 m;
  - Capacity_2: max 3.1 m^3;
  - Capacity_3: max load 1000 kg;
  - Cost per unit time: 14 EUR/h, taking into account the average cost of the monthly rent of a van and the cost of the average salary of a van driver in Slovenia;
  - Cost per unit distance: 0.128 EUR/km, diesel drive, 8.0 L/100 km, 1.6 EUR/L;
  - Start depo service time: 10 min;
  - End depo service time: 20 min.
- Truck with trailer:
  - Capacity_1: max 20 pallets 1.2 × 1.0 × 1.0 m;
  - Capacity_2: max 48 m^3;

- Capacity_3: max load 20,000 kg;
- Cost per unit time: 17 EUR/h, taking into account the average cost of the monthly rent of a truck with trailer and the cost of the average salary of a truck driver in Slovenia;
- Cost per unit distance: 0.24 EUR/km, diesel drive, 15.0 L/100 km, 1.6 EUR/L;
- Start depo service time: 15 min;
- End depo service time: 30 min.

- Truck:
  - Capacity_1: max 10 pallets 1.2 × 1.0 × 1.0 m;
  - Capacity_2: max 24 m^3;
  - Capacity_3: max load 10,000 kg;
  - Cost per unit time: 15 EUR/h, taking into account the average cost of the monthly rent of a truck and the cost of the average salary of a truck driver in Slovenia;
  - Cost per unit distance: 0.16 EUR/km, diesel drive, 10.0 L/100 km, 1.6 EUR/L;
  - Start depo service time: 15 min;
  - End depo service time: 30 min.

Table 2. Input data for Scenario 1.

Input Data	**Vehicle**		
	Truck1	**Van1**	**Forklift1**
Start Depot/End Depot	Truck Parking	Van Parking	Forklift Parking
Start Depot Service Time [min]	15	10	5
End Depot Service Time [min]	30	20	10
Earliest/Latest Start Time	6:00 a.m.	6:00 a.m.	6:00 a.m.
Capacity: Number of pallets	10	2	1
Cost per Unit Time [EUR/min]	0.25	0.23	0.21
Cost per Unit Distance [EUR/km]	0.16	0.13	0.02
Break Service Time [min]	30	30	30
Break (from-to)	9:30 a.m.–10:00 a.m.	9:30 a.m.–10:00 a.m.	9:30 a.m.–10:00 a.m.

Table 3. Input data for Scenario 2.

Input Data	**Vehicle**		
	Truck1	**Truck2 with Trailer**	**Truck3**
Start Depot/End Depot	Truck Parking	Truck Parking	Truck Parking
Start Depot Service Time [min]	15	15	15
End Depot Service Time [min]	30	30	30
Earliest/Latest Start Time	6:00 a.m.	6:00 a.m.	6:00 a.m.
Capacity: Number of pallets	10	20	10
Cost per Unit Time [EUR/min]	0.25	0.29	0.25
Cost per Unit Distance [EUR/km]	0.16	0.24	0.16
Break Service Time [min]	30	30	30

Table 4. Input data for Scenario 3a.

Input Data	Vehicle			
	Truck1	Truck2 with Trailer	Truck3	
			6:00 a.m.–7:30 a.m.	11:30 a.m.–2:00 a.m.
Start Depot/End Depot	Truck Parking	Truck Parking	Truck Parking	Truck Parking
Start Depot Service Time [min]	15	15	15	0
End Depot Service Time [min]	30	30	0	30
Earliest/Latest Start Time	6:00	6:00	6:00	11:30
Capacity: Number of pallets	10	20	10	10
Cost per Unit Time [EUR/min]	0.25	0.29	0.25	0.25
Cost per Unit Distance [EUR/km]	0.16	0.24	0.16	0.16
Break Service Time [min]	30	30	No break	No break

Table 5. Input data for Scenario 3b.

Input Data	Vehicle			
	Truck1	Truck2 with Trailer	Van1	
			6:00 a.m.–7:30 a.m.	12:00 a.m.–2:00 p.m.
Start Depot/End Depot	Truck Parking	Truck Parking	Van Parking	Van Parking
Start Depot Service Time [min]	15	15	10	0
End Depot Service Time [min]	30	30	0	20
Earliest/Latest Start Time	6:00 a.m.	6:00 a.m.	6:00 a.m.	12:00 a.m.
Capacity: Number of pallets	10	20	2	2
Cost per Unit Time [EUR/min]	0.25	0.29	0.23	0.23
Cost per Unit Distance [EUR/km]	0.16	0.24	0.13	0.13
Break Service Time [min]	30	30	No break	No break

Scenario 1 is the initial scenario, including a truck, van, and forklift in a vehicle fleet, used for checking if this fleet can realize daily orders. All the other scenarios were designed as an attempt to achieve zero total violation time (TV = 0). The scenario is recognized as successful when it realizes all daily orders in the required sequence and inside the required time windows. Successful scenarios can be ranked further using cost, fuel consumption, etc.

All four scenarios are presented in more detail in the following two subchapters.

3.5.1. Scenario 1

Scenario 1 includes the following three vehicles: Truck1, Van1, and Forklift1 (Table 2). Each vehicle has its own start and end service time. The shortest service time is determined for Forklift1, the only electric vehicle. Forklift1 can carry only one box pallet at a time; Van1 can carry two pallets; and Truck1 can carry ten pallets. Forklift1 operates with the lowest cost per kilometer due to its electric power. All vehicles are stationary during a flexible half-hour lunch break, starting between 9:30 and 10:00 a.m.

In Scenario 1, a Van1 is specialized to carry only tools from the TS to PHI and PHII and vice versa. Similarly, Forklift1 primarily carries only box pallets with waste from PHI and PHII to the WY, and empty box pallets back from WY to PHI and PHII. Truck1 transports materials from the WM to PHI and PHII and finished products from PHI and PHII to the WFG. Hard time windows were defined for all orders to ensure their timely realization.

3.5.2. Scenario 2

Hard time windows were determined to be sure that Scenario 2 would realize all orders in the required time windows. Scenario 2 includes three trucks. The second (Truck2) out of the three has a trailer (Table 3). Truck1 and Truck3 in Scenario 2 have the same characteristics as Truck1 from Scenario 1. A trailer has the same capacity as a truck. A

truck with a trailer can carry a doubled number of pallets compared to the truck itself. The increased capacity leads to higher vehicle costs per minute and kilometer. Box pallets with waste and empty box pallets can be assigned only to Truck1. Any of the three trucks can realize the rest of the orders.

3.5.3. Scenario 3a

Scenario 3a was built to realize the orders and optimize the fleet and workers' performance. Hard time windows were retained because they ensure the realization of orders in the required time windows. Scenario 3a includes the same vehicles as Scenario 2, with the difference being that Truck3 operates for only 4 h (Table 4). As the orders require the most transports in the morning and towards the end of the shift, the already-reduced working hours for Truck3 are split into two operating periods, namely from 6:00 a.m. to 7:30 a.m. and from 11:30 a.m. to 2:00 p.m. Box pallets with waste and empty box pallets are assigned only to Truck1. Any of the three trucks can realize the rest of the orders.

3.5.4. Scenario 3b

Scenario 3b further optimizes the vehicle fleet by replacing Truck3, with a smaller and cheaper Van1. Operating hours for Van1 were reduced compared to Truck3 in Scenario 2. Van1 operates for three and a half hours per day in two operating periods from 6:00 a.m. to 7:30 a.m. and from 12:00 a.m. to 2:00 p.m. Van1 can transport all kinds of orders except box pallets with waste and empty box pallets, which are assigned only to Truck1. It is assumed that Scenario 3b could be the optimal to realize the given orders.

4. Results

We started the decision-making process for configuring the future internal transport system in the manufacturing plant's outdoor area by simulating the initial Scenario 1. Scenario 1 was configured based on the company's experience with internal outdoor transport. The result of the order-realization simulation with the help of Scenario 1 answers whether the initially planned capacities of the vehicle fleet and drivers ensure the continuous execution of production processes.

Scenario 1 simulation results revealed its shortcomings. Scenario 1 was revealed as inappropriate, as not all orders were fulfilled within the time windows required by production. Van1 and Forklift1 carried out all assigned orders (pallets with tools, box pallets with waste, and empty box pallets) within the required time windows and completed the work within their work shift before 2 p.m. However, Truck1 produced the following outcomes:

- Fully realized 30.77% of the assigned orders (pallets with material and finished products) within the required time windows;
- Partially realized 38.47% of the assigned orders within the required time windows.

Partial realization means, for example, that Truck1 had to deliver a group of orders of ten pallets to PHI between 10:00 a.m. and 11:00 a.m., but it delivered only four pallets in the required time window, while it delivered the remaining six pallets after 11:00 a.m.

Furthermore, Truck1 carried out 30.77% of the assigned orders after closing the time windows, thus completing the shift at 5:23 p.m. instead of 2:00 p.m. Considering all vehicles in Scenario 1, they produced the following outcomes (Table 6):

- Fully realized 59.09% of the assigned orders in the required time windows;
- Partially realized 22.73% of the assigned orders in the required time windows;
- Failed to realize 18.18% of the assigned orders.

Based on the simulation experience with Scenario 1, Scenario 2 was configured to realize all orders within the required time windows. With Scenario 3a and Scenario 3b, the vehicle fleet was further optimized regarding vehicle capacity and operating hours to a scenario that could most efficiently perform all orders within the required time windows.

In the following, four scenarios are compared according to the output values of the VRP analysis.

Table 6. Share of fully realized/partially realized/unrealized orders within the required time windows for Scenario 1.

Vehicle Type	Fully Realized Orders (%)	Partially Realized Orders (%)	Unrealized Orders (%) *
Truck1	30.77	38.47	30.77
Van1	100.00	0	0
Forklift1	100.00	0	0
Together	59.09	22.73	18.18

* Orders fall entirely out of planned time windows.

4.1. Results of Scenario 1 Simulation

Results from the simulation of Scenario 1 are presented in Table 7.

Table 7. Achieved performance indicators with Scenario 1 simulation.

Performance Indicator	Truck1	Van1	Forklift1	Total for Scenario
Order Count [pallets]	185	12	12	209
Total Travel Time [min]	53.09	25.63	39.76	118.48
Total Wait Time * [min]	0	254.45	272.08	526.53
Total Distance [km]	12.47	5.80	8.61	26.89
Time Cost [EUR]	170.77	93.53	99.32	363.62
Distance Cost [EUR]	1996.12	742.84	137.75	2876.71
Total Cost [EUR]	2166.89	836.37	237.07	3240.33

* The route may arrive at the order before the beginning of one of the order's time windows, in which case there is a wait time at the order. The sum of all wait times for the scenario is the total wait time.

In Scenario 1, the total distance traveled is high since the van can carry two pallets per drive and forklift one pallet per drive. Because the van and forklift carry only box pallets with waste, empty box pallets, or pallets of tools, they accumulate a significant wait time, namely 8.76 h per working day. Truck1 carries 185 pallets of material and finished products per day, causing the operating period to be delayed until 5:23 p.m. As a result, Truck1 operates with the highest time and distance costs compared to other vehicles in Scenario 1.

The main disadvantages of Scenario 1 are the high violation time, high wait time, high total time, and high time costs. Internal transport occurs in the central part of the manufacturing plant's outdoor area, and, while faster, 40 km/h one-way and two-way roads on the right side of the outdoor area (Figure 1) remain unused.

4.2. Results of Scenario 2 Simulation

In Scenario 2, the vehicle fleet was selected as a way to increase the overall capacity and, in this way, achieve the complete realization of the orders. The van (Van1) and the forklift (Forklift1) from Scenario 1 were replaced with a truck (Truck3) and a truck with a trailer (Truck2 with a trailer). Results from the Scenario 2 simulation (Table 8) revealed that Truck1 realized the majority of orders (39.7%). Its wait time was the smallest of all vehicles at 13.2 min. Truck1 traveled the longest distance (10.75 km) and had the longest travel time (60.7 min). Truck2 with a trailer did not prove to be a flexible solution. It transported 45 pallets in total (21.5%) and had the longest wait time (225.5 min), and 69% of the total wait time for the Scenario 2 simulation.

Time and total costs in Scenario 2 are higher than in Scenario 1. Distance costs are lower than in Scenario 1. Although Scenario 2, unlike Scenario 1, fulfills orders in the required time windows, it has low productivity and no outstanding advantages. Scenario 2 is the only scenario where all three vehicles use the faster 40 km/h one-way and two-way roads on the right side of the outdoor area (Figure 1).

Table 8. Achieved performance indicators with Scenario 2 simulation.

Performance Indicator	Truck1	Truck2 with Trailer	Truck3	Total for Scenario
Order Count [pallets]	81	45	83	209
Total Travel Time [min]	60.69	22.18	36.95	119.82
Total Wait Time [min]	13.18	225.46	87.92	326.56
Total Distance [km]	10.75	5.57	9.69	26.01
Time Cost [EUR]	118.97	137.06	116.47	372.50
Distance Cost [EUR]	1720.09	1337.47	1550.57	4608.13
Total Cost [EUR]	1839.06	1474.53	1667.04	4980.63

4.3. Results of Scenario 3a Simulation

Scenario 3a was the first attempt to optimize Scenario 2. The vehicles are the same as in Scenario 2. In Scenario 3a, the operating hours for Truck3 were reduced to four hours, split into two operating time windows. The first operating time window takes place from 6:00 a.m. to 7:30 a.m. and the second from 11:30 a.m. to 2:00 p.m. Truck2 with a trailer transports the most pallets (44% of all) in a little more than half of Truck1's travel time due to its larger capacity (Table 9). Truck2 with a trailer is, here, better utilized than in Scenario 2. Its wait time is largely reduced but still represents 69.6% of all wait time in the Scenario 3a simulation. Truck3 has significantly lower total costs than in Scenario 2 due to the shortened and split operating time. As a result, the total costs of Scenario 3a are lower than those of Scenario 2. Scenario 2 and Scenario 3a supply the production with all orders in the required time windows. The main advantages of Scenario 3a are its 5.7% lower total cost, 63.4% smaller total wait time, 10.6% shorter total distance, and 4.6% smaller total travel time than those achieved with Scenario 2.

Table 9. Achieved performance indicators with Scenario 3a simulation.

Performance Indicator	Truck1	Truck2 with Trailer	Truck3 *	Total for Scenario
Order Count [pallets]	82	92	35	209
Total Travel Time [min]	60.03	36.31	17.98	114.32
Total Wait Time [min]	9.83	83.33	26.53	119.69
Total Distance [km]	11.37	8.29	3.58	23.25
Time Cost [EUR]	118.97	137.93	55.13	312.03
Distance Cost [EUR]	1819.74	1990.59	573.57	4383.90
Total Cost [EUR]	1938.71	2128.52	628.70	4695.93

* 6:00 a.m.–7:30 a.m. and 11:30 a.m.–2:00 p.m.

In Scenario 3a, Truck1 and Truck3 use routes in the central part of the outdoor area, while Truck2 with a trailer also uses roads on the right side of the outdoor area (Figure 1).

4.4. Results of Scenario 3b Simulation

Scenario 3b was the second attempt to optimize Scenario 2. Scenario 3b tests if Van1 could replace Truck3. The operating hours for Van1 were reduced to three and a half hours, split into two operating time windows. The first operating time window takes place from 6:00 a.m. to 7:30 a.m. and the second from 12:00 a.m. to 2:00 p.m. One of Van1's advantages is that it needs less service time at the beginning and end of the working day than a truck. Results from Scenario 3b unexpectedly revealed that Van1 in Scenario 3b has 92.9% higher distance cost than Truck3 in Scenario 3a (Tables 9 and 10). Namely, Van1, due to its limited capacity of two pallets, transported 17.14% fewer pallets than Truck3 and achieved a 70.33% longer total distance than Truck3.

Table 10. Achieved performance indicators with Scenario 3b simulation.

Performance Indicator	Truck1	Truck2 with Trailer	Van1 *	Total for Scenario
Order Count [pallets]	83	97	29	209
Total Travel Time [min]	58.71	43.33	41.18	143.22
Total Wait Time [min]	7.15	59.27	10.43	76.85
Total Distance [km]	11.52	7.62	12.07	31.23
Time Cost [EUR]	118.97	137.93	43.92	300.82
Distance Cost [EUR]	1843.76	1830.81	1545.89	5220.46
Total Cost [EUR]	1962.73	1968.74	1589.81	5521.28

* 6:00 a.m.–7:30 a.m. and 12:00 a.m.–2:00 p.m.

The advantages of Scenario 3b are improved utilization and reduced total wait time of Truck2 with a trailer compared to Scenario 2 and Scenario 3a. Scenario 3b makes the best use of a truck with a trailer. The disadvantages of Scenario 3b are that it has the highest distance cost (11.7% higher than the second highest) and the highest total cost (9.8% higher than the second highest).

4.5. Comparison of Simulation Results of Different Scenarios

Table 11 compares the achieved performance indicators of the four scenarios included in the final consideration. The scenarios were developed gradually in ArcGIS Pro, following decision-making steps regarding the characteristics of order time windows and vehicle fleet composition. Scenario 2 was the first that successfully realized the client's internal transport services' orders in the manufacturing plant's outdoor area. By configuring Scenario 3a and Scenario 3b in an ArcGIS Pro software environment, an attempt was made to improve the performance indicators by reconfiguring the vehicle fleet.

Table 11. Comparison of achieved performance indicators.

Performance Indicator	Scenario 1	Scenario 2	Scenario 3a	Scenario 3b
Fulfillment of all orders	no	yes	yes	yes
Time Cost [EUR]	363.62	372.50	312.03	300.82
Distance Cost [EUR]	2876.71	4608.13	4383.90	5220.46
Total Cost [EUR]	3240.33	4980.63	4695.93	5521.28
Total Time [min]	1568.00	1414.37	1172.01	1143.06
Total Travel Time [min]	118.48	119.82	114.32	143.22
Total Distance [km]	26.89	26.01	23.25	31.23
End Time	17:23	13:56	13:56	13:56
Total Wait Time [min]	526.53	326.56	119.69	76.85
Total Violation Time	428 h 52 min	0 h 0 min	0 h 0 min	0 h 0 min

In addition to Scenario 2, 3a, and 3b, we also included Scenario 1 in the final decision process, although $TV_1 > 0$ and $T_1 > 480$ min. Scenario 1 should be eliminated from the final decision-making process because it does not fulfill all the customer's orders in the required time windows, and it extends the delivery of transport services over two shifts. Scenario 2, 3a, and 3b are suitable for implementation in practice.

If we continued to reconfigure settings of road regimes and vehicle fleet composition variants in ArcGIS Pro, the set of scenarios suitable for implementation would increase further. The purpose of the article is not to find the optimal solution for the given case but to show the decision-making process and the potential of decision-making support when using ArcGIS Pro software. According to the head of the logistics department, the achieved values of the performance indicators according to Scenario 2, 3a and 3b are completely satisfactory, and he saw no reason for further searching and simulating in ArcGIS Pro. Four scenarios were enough to define the vehicle fleet and satisfactorily improve the internal outdoor area transport as much as possible.

The simulation in ArcGIS reveals to the decision makers the values for various performance indicators and, simultaneously, allows the decision makers to configure new scenarios based on the behavior of the already simulated scenarios and try to influence those performance indicators that are most important for the company (Figure 3).

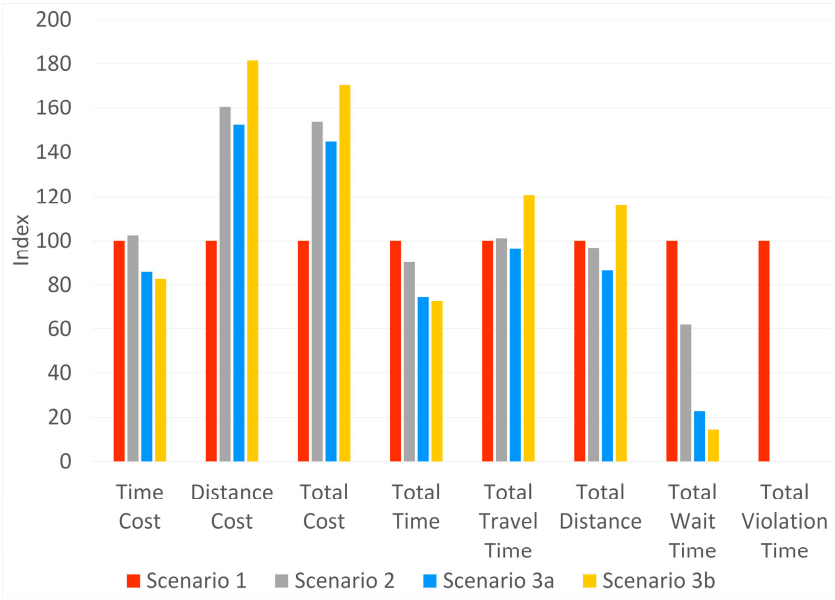


Figure 3. Visualization of achieved performance indicators between individual scenarios.

Comparing Scenario 2, Scenario 3a, and Scenario 3b, which all realize orders within the required time windows, Scenario 3a has the lowest total cost and total distance. Scenario 3b has the lowest total time and time cost, and best utilizes vehicles with the smallest total wait time. Performance indicators of Scenario 2 nicely follow the results of scenarios 3a and 3b, but do not reach outstanding values.

Traffic is spread over all available transport routes within the company complex in all four scenarios under consideration (Figures 4–7).

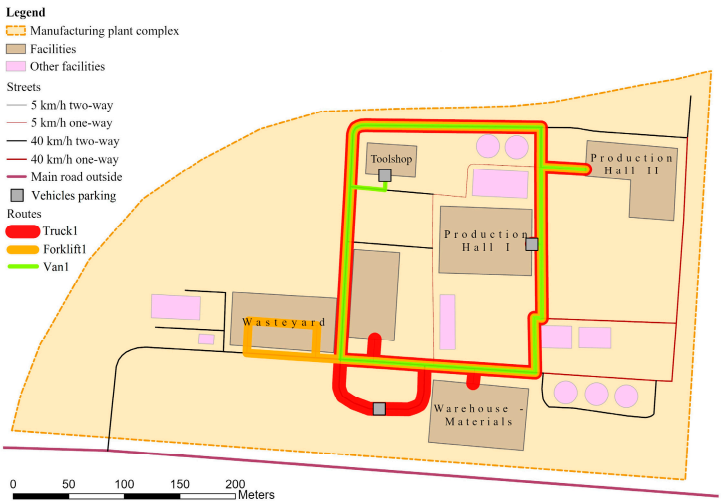


Figure 4. Manufacturing plant layout with route results for Scenario 1.

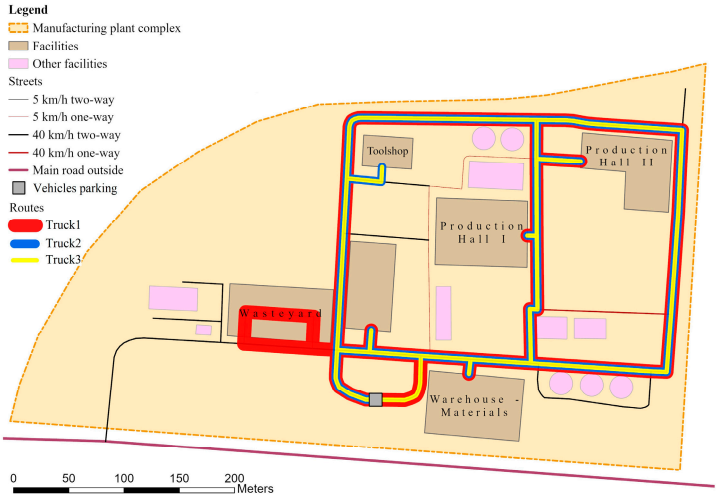


Figure 5. Manufacturing plant layout with route results for Scenario 2.

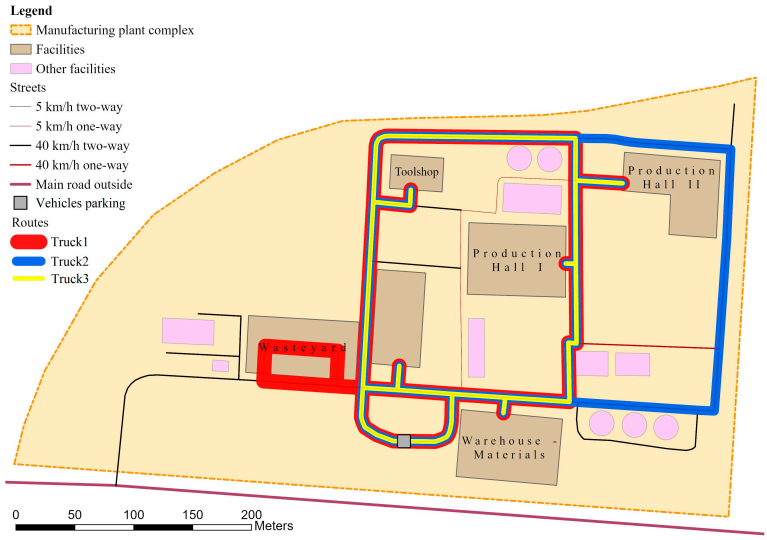


Figure 6. Manufacturing plant layout with route results for Scenario 3a.

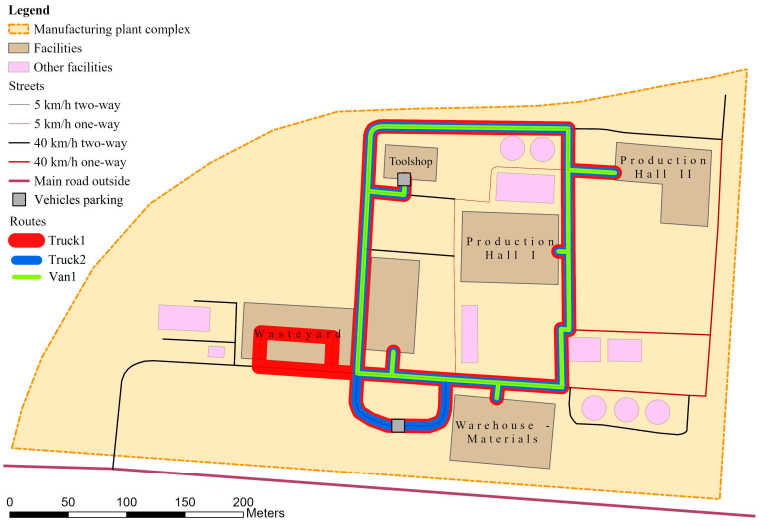


Figure 7. Manufacturing plant layout with route results for Scenario 3b.

Simulation can help decision makers choose the type of vehicles in their fleet. In the case study, four types of vehicles were tested, i.e., a forklift, a van, a truck, and a truck with a trailer. Vehicles are distinguished from each other using their capacity, operating costs, maintenance costs, and type of fuel. The truck (Truck1) is the best-utilized vehicle in all the simulated scenarios. This conclusion is based on it having the almost always maximum number of transported pallets with the lowest total wait times (Tables 5–8). In Scenario 3b, a truck with a trailer, that has twice the capacity of only a truck, transported only 14.43% more pallets than a truck with an 87.9% longer total wait time. A truck with a trailer is the vehicle with the highest capacity of the vehicles under consideration but not enough flexibility for short transportation distances in the manufacturing plant's yard.

To summarize, a truck with a trailer did not realize many more orders than a truck without a trailer in the same amount of time. Furthermore, a truck with a trailer produced the highest wait time in all three scenarios in which it appears. Only in Scenario 3b did the total wait time for a truck with the trailer fall marginally below 1 h. From the point of view of total cost, a truck with a trailer is the favorable option since, compared to a truck without a trailer, it does not produce significantly higher costs. Low total costs are related to the short distances traveled due to its larger capacity and long loading and unloading times.

A van and forklift represent affordable transport variants. Due to their small capacity, one pallet for a forklift and two pallets for a van, they are very flexible with fast response times. When powered with electricity, they are considered green vehicles that can be powered using electricity produced in the company's solar power plant. A forklift was used only in Scenario 1. It was assigned to specific, infrequent orders, which caused a high total wait time. The forklift was eliminated from later scenarios, as the van proved to be a more responsive and flexible solution. A van proved to be a promising solution in Scenario 3b, where it was allowed to transport all kinds of orders except box pallets with waste and empty box pallets. It was used for only three and a half hours per day, but it was excellently utilized with only 10.4 min of total wait time. However, Van1 in Scenario 3b incurs a considerable distance cost, as it can carry only two pallets at a time and, therefore, travels a long distance. This contributes to the fact that the total cost of Scenario 3b is the highest. Although a van operates for half the operating time, it contributes almost the same share of costs to the total cost as a truck and a truck with a trailer. From this, it could be concluded that engaging a truck for part of the time in Scenario 3a is a better solution than engaging a van for part of the time in Scenario 3b.

We have observed that each scenario considered has its advantages and disadvantages. Examining tables with results and comparing bar charts can be quite tiring and even misleading for the decision maker. The decision-making group thus continued to make decisions in accordance with the AHP methodology. First, the hierarchy of the problem was defined as shown in Figure 8.

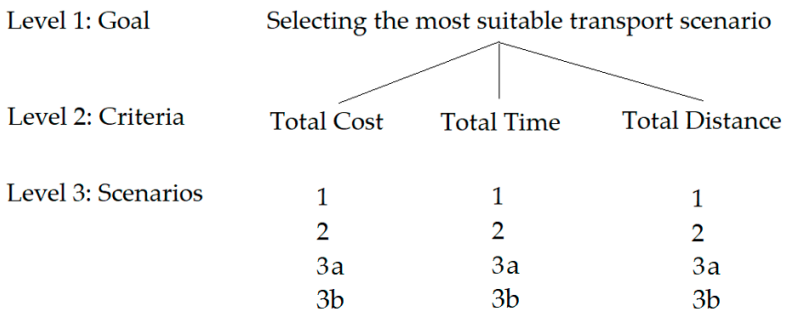


Figure 8. The hierarchy of the problem.

Table 12 summarizes the details of the scenarios in the selection with defined criteria and alternatives.

Table 12. Criteria and the list of alternatives.

		Criteria		
		1	**2**	**3**
Alternative	**Scenario**	**Total Cost [EUR]**	**Total Time [min]**	**Total Distance [km]**
1	Scenario 1	3240.33	1568.00	26.89
2	Scenario 2	4980.63	1414.37	26.01
3	Scenario 3a	4695.93	1172.01	23.25
4	Scenario 3b	5521.28	1143.06	31.23

The decision-making group indicated preferences for decision alternatives regarding their contributions to criteria (Tables 13–15). In doing so, they derived from the pair-wise comparison scale for AHP preferences shown in Table 16.

Table 13. Pair-wise comparison matrix for total time.

	Scenario 1	**Scenario 2**	**Scenario 3**	**Scenario 4**
Scenario 1	1	1/3	1/5	1/7
Scenario 2	3	1	1/4	1/6
Scenario 3a	5	4	1	1/2
Scenario 3b	7	6	2	1

Table 14. Pair-wise comparison matrix for total cost.

	Scenario 1	**Scenario 2**	**Scenario 3**	**Scenario 4**
Scenario 1	1	3	3	7
Scenario 2	1/3	1	1/2	2
Scenario 3a	1/3	2	1	3
Scenario 3b	1/7	1/2	1/3	1

Table 15. Pair-wise comparison matrix for total distance.

	Scenario 1	**Scenario 2**	**Scenario 3**	**Scenario 4**
Scenario 1	1	1/2	1/4	3
Scenario 2	2	1	1/3	3
Scenario 3a	4	3	1	5
Scenario 3b	1/3	1/3	1/5	1

Table 16. Comparison scale for AHP preferences [41,42].

Numerical Values	**Description**	**Explanation**
1	Equal importance of both elements	Two elements contribute equally
3	Moderate importance of one element over another	Experience and judgment favor one element over another
5	Strong importance of one element over another	An element is strongly favored
7	Very strong importance of one element over another	An element is very strongly dominant
9	Extreme importance of one element over another	An element is favored by at least one order of magnitude
2, 4, 6, 8, 10	Intermediate values between two adjacent elements	Used to compromise between two judgements

The analyst synthesized the pair-wise comparison matrices (Tables 17–19); calculated the priority vectors for the criteria of total time, total cost, and total distance; calculated the consistency ratios; calculated λ_{max}, consistency indexes (CI); selected appropriate values for the random consistency ratio from Table 20; and checked the consistency of the pair-wise comparison matrix to check whether the decision makers' comparisons were consistent.

Table 17. Synthesized matrix for total time.

	Scenario 1	Scenario 2	Scenario 3	Scenario 4	Priority Vector
Scenario 1	0.06	0.03	0.06	0.08	0.06
Scenario 2	0.19	0.09	0.07	0.09	0.11
Scenario 3a	0.31	0.35	0.29	0.28	0.31
Scenario 3b	0.44	0.53	0.58	0.55	0.52
				Sum	1.00

λ_{max} = 4.12, CI = 0.0406, RI = 0.9000, CR = 0.0451 < 0.1.

Table 18. Synthesized matrix for total cost.

	Scenario 1	Scenario 2	Scenario 3	Scenario 4	Priority Vector
Scenario 1	0.55	0.46	0.62	0.54	0.54
Scenario 2	0.18	0.15	0.10	0.15	0.15
Scenario 3a	0.18	0.31	0.21	0.23	0.23
Scenario 3b	0.08	0.08	0.07	0.08	0.08
				Sum	1.00

λ_{max} = 4.04, CI = 0.0137, RI = 0.9000, CR = 0.0152 < 0.1.

Table 19. Synthesized matrix for total distance.

	Scenario 1	Scenario 2	Scenario 3	Scenario 4	Priority Vector
Scenario 1	0.14	0.10	0.14	0.25	0.16
Scenario 2	0.27	0.21	0.19	0.25	0.23
Scenario 3a	0.55	0.62	0.56	0.42	0.54
Scenario 3b	0.05	0.07	0.11	0.08	0.08
				Sum	1.00

λ_{max} = 4.11, CI = 0.0375, RI = 0.9000, CR = 0.0417 < 0.1.

Table 20. Average random consistency [41,42].

Size of Matrix	1	2	3	4
Random consistency (RI)	0	0	0.58	0.90

As the calculated consistency ratio (CR) was, for all criteria, less than 0.1, the decision-making group set priorities for three criteria in terms of the importance of each in contributing to the initially stated goal. Table 21 shows the pair-wise comparison matrix and the priority vector for the total time, total cost, and total distance.

Table 21. Pair-wise comparison matrix for the three criteria.

	Total Cost	Total Time	Total Distance	Priority Vector
Total Cost	1	1/2	4	0.2956
Total Time	2	1	10	0.6357
Total Distance	1/4	1/10	1	0.0687
			Sum	1.00

λ_{max} = 3.01, CI = 0.0027, RI = 0.58, CR = 0.0048 < 0.1.

The analyst combined the criterion priorities and the priorities of each decision alternative relative to each criterion in order to develop an overall priority ranking of the decision's alternative which is termed as the priority matrix (Table 22).

Table 22. Priority matrix for scenario selection.

	Total Cost (0.2956)	Total Time (0.6357)	Total Distance (0.0687)	Overall Priority Vector
Scenario 1	0.54	0.06	0.16	0.21
Scenario 2	0.15	0.11	0.23	0.13
Scenario 3a	0.23	0.31	0.54	0.30
Scenario 3b	0.08	0.52	0.08	0.36

The scenarios are ranked according to initially defined priorities, as follows: Scenario 3b, Scenario 3a, Scenario 1, and Scenario 2.

5. Discussion

The article presents the use of ArcGIS Pro software for testing different arrangements of internal transport in the yard of a company so that the decision makers could realize the significance of the savings they can expect due to a structured consideration of the ways of carrying out internal outdoor area transport in the yard of their company. In doing so, decision makers do not need to think about VRP algorithms or search for the right one. The software supports multi-criteria decision-making and the testing of different scenarios built on the same or different process resources, system infrastructure, and organizational settings. Chapters 2 and 3 support an affirmative answer to the first research question, namely, that ArcGIS Pro software can be used for simulating different variants of the implementation of internal transport in a manufacturing plant's outdoor area.

5.1. Benefits of Using ArcGIS Pro for Planning Internal Outdoor Transport

Based on testing the ArcGIS Pro software for planning internal outdoor area transport, which is not in practice in the field of transport research, it is possible to discuss the advantages and disadvantages of its use for similar challenges. After experimental use, we claim that ArcGIS Pro software can be used for planning internal transport in a manufacturing plant's outdoor area. Preparing to use the program is very similar to the general implementation of computer programs. It starts with purchasing a license, user training of at least one employee, preparing the layout of the manufacturing plant's complex in GIS, and preparing the transport network model. From this step, further customization is completed for each model individually. It is necessary to (1) prepare the list of orders in a software program that uses spreadsheets to organize numbers and data with formulas and functions (for example any version of MS Excel) or csv format (example in Table 1); (2) create, update, and select the vehicle fleet; and (3) define traffic regimes, road closures, and additional settings (time window importance, transit time importance, cluster). Additional settings allow for modelling of the design to simply determine the decision rules for the simulation behavior, without programing knowledge, and within ArcGIS, before using an MCDA. For example, the transit time importance setting allows for rating the importance of reducing excess transit time, which is the amount of time exceeding the time required to travel directly between the paired orders.

In accordance with what has been written, we claim that the use of the program is quite simple and can be learned quickly. Decision makers can use the program themselves. When the decision maker sets the scenario, the program creates turn-by-turn instructions for navigating a route, which can be handed over directly to the driver:

- Begin route Truck1
- 1: Start at truck parking
  Time window: 20 November 2023 06:00–20 November 2023 14:00
  Service time: 15 min

- 2: Go east on 40 km/h two-way road
  Drive 73.8 m~< 1 min
  3: . . .
  . . .
  459: . . .
- 460: Finish at truck parking, on the right
  Time window: 20 November 2023 06:00–20 November 2023 14:00
  Service time: 30 min
- Total time: 7 h 56 min
  Total distance: 11,373.4 m
  Total wait time: 10 min
  Start time: 20 November 2023 06:00
  Finish time: 20 November 2023 13:56
  End of route Truck1

The function of a hard time window is indispensable. Highlighting the example of transporting a box pallet with waste from the PH1 to the WY and then returning an empty box pallet to the PH1, without the function of a hard time window, it could be that the vehicle would transport an empty box pallet back to the PH1 before even transporting a box pallet with waste to the WY, which is unrealistic in practice. Therefore, we recommend defining the time window for a box pallet with waste and the empty box pallet so that they do not overlap and using the hard-time-window function in parallel.

5.2. Limitations of Using ArcGIS Pro for Planning Internal Outdoor Transport

We recommend optimally defining the time windows for the orders, i.e., neither too narrow nor too wide. In modeling, the cooperation of the customers is necessary because, through participating in the decision-making process, they reconsider the rationality and necessity of their requests. If the time windows for the orders are too narrow, a given vehicle fleet cannot fulfill all orders in time. On the contrary, if the time windows for the orders are too wide, the VRP solver can over-shuffle the desired order sequence in search of the optimal solution.

Testing the ArcGIS Pro Network Analyst revealed three shortcomings. The first is the lack of a tool explicitly for reducing the wait time of a specific vehicle, which, on the other hand, could result in higher total costs of the solution. The second is the inability of the software to define the split work time of a vehicle. Instead, duplication of the vehicle was required with one vehicle for each part of the split time. The third is the inability to determine the desired level of vehicle occupancy. The vehicle occupancy function would allow loading of the vehicle to the desired maximum. On the other hand, this could contribute to a higher total cost of the solution.

5.3. Insight into Integrating AHP into Modeling Using ArcGIS Pro Software?

The integration of the AHP into modeling using ArcGIS Pro proved useful on the managers' side. Their opinions were gathered through an interview. Using ArcGIS Pro independently faced them with difficult decision making between several viable scenarios. When deciding between them, it was difficult for them to consider several decision criteria in parallel, although there were only three. It would be possible to prioritize a scenario that does not meet their strongest preference.

The AHP method was rated as easy to learn and somewhat more difficult to use. The most difficult aspect was setting preferences for decision alternatives regarding their contributions to criteria and set priorities for three criteria in terms of the importance of each in contributing to the initially stated goal. The heads of the logistics and production departments recognized determining priorities as challenging. In this process, the two managers represented the interests of their departments. Coordinating priorities between the two departments or finding a compromise was recognized as even more challenging. The heads of the logistics and production departments agree that the company's CEO,

who emphasized the company's interests at key points, helped a lot to determine the compromise.

As we stated in the theoretical background, the most recognized drawback of the AHP is subjectivity. Preferences will always differ among decision makers. For this reason, it does not make sense to ignore the importance of AHP implementation in group decision making. It is important for decision makers to become very familiar with the decision-making process according to AHP and to learn about examples of good and bad practice. The existing literature, which shows a high level of study of the applicative use of the AHP, can be of great help to them, for example [54]. Informed decision makers can implement AHP decision making in a way that achieves advantages and skillfully avoids disadvantages.

6. Conclusions

ArcGIS Pro is an excellent and easy tool for decision makers when planning internal transport in a manufacturing plant's outdoor area. Of course, the field of its application is wide. Within this article, we only examined a narrow segment. The tool is suitable for supporting strategic and tactical decision making, but we do not see it as a tool for operational decision making. Support for operational management is provided by special dedicated software such as a transportation management system, route planning, a warehouse management system, and others.

The program allows the decision maker to configure a fleet of vehicles, prepare a starting point for hiring drivers, prepare starting points for organizing transport routes on external surfaces owned by the company, check the feasibility of realizing customer orders, and support multi-criteria decision making. Our challenge is not to improve the program, but to think about how decision makers could use its functionality to the greatest extent possible. We have established some of this through the present study, but there are still opportunities for further studies. One such opportunity could be applying the ArcGIS Pro software for determining bottlenecks of orders in connection with vehicle availability. This could further contribute to easier decision making regarding the type and working hours of vehicles.

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