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Parking Lots Assignment Algorithm for Vehicles Requiring Specific Parking Conditions in Vehicle Routing Problem

IGOR BETKIER[1], JOLANTA KATARZYNA ZAK[2], AND SZYMON MITKOW[1]

[1]Faculty of Security, Logistics and Management, Military University of Technology, 00-908 Warsaw, Poland
[2]Faculty of Transport, Warsaw University of Technology, 00-662 Warsaw, Poland

Corresponding author: Igor Betkier (igor.betkier@wat.edu.pl)

ABSTRACT Based on the analysis of the current literature, mathematical modelling of the studied phenomenon was carried out. It was conducted according to the graph theory for vehicles transporting dangerous, oversized, and valuable cargo, moving within a transport network. The mapping of the parking areas included organisational, technical, and security aspects. The main algorithm determines the driving routes based on the parkings that meet the requirements specified by the carrier. These routes can ultimately be analysed and evaluated based on the parameters resulting from the formulated criterion functions. To verify the performance of the algorithm, its implementation was carried out in a computer environment using the Neo4j graph database. The transport network, consisting of 462 transport nodes and 602 transport links, was mapped based on the real national road network of the province in Poland. Data from 113 parking locations in the study area were included in the analysis. The research covered a total of three case studies, one for each vehicle type requiring specific parking conditions, for various input data. The results obtained allowed us to assess the validity of selecting particular routes and evaluating the scalability of the solution. The result of this work is a method, which, on the one hand, fits the current transportation requirements. On the other hand, it lends itself to scaling, extension by additional logical constraints, and is compatible with modern parking systems.

INDEX TERMS Vehicle routing problem, parking assignment, parking requirements, transport planning, transportation software, truck driver scheduling.

I. INTRODUCTION

The vehicle routing problem (VRP) is a topic that, despite having been first described in the mid-twentieth century, definitely stands out in the background of modern transportation-related research [1]. In accordance with Demir *et al.* [2], these issues will be continued based on environmental considerations, continuously changing market needs, and forecasting models.

VRP is applicable to problems based on real-time decision making [3], but it also supports the planning process of a transportation task by determining a detailed route for a set of criteria before starting a trip [4]. In numerous cases, despite the complexity of analysing the VRP problem for a defined transportation segment, modern researchers tend to focus on the movement of the vehicle itself without considering aspects related to the organisation of parking [5]–[7].

Stops along a vehicle's route may be crucial, and their nature varies. Schiffer *et al.* in their work [8] examined VRP issues related to the routing problem with intermediate stops (RPIS), for which they identified several main reasons for RIPS, including intermediate stops for rests and breaks (ISRB), as well as those imposed by regulations. The ISRB in the above publication stood out from the remaining ones because of a much smaller number of publications dealing with the subject.

In the literature, ISRB aspects tend to be considered more often in the context of urban transport and the related problem of parking space availability for passenger cars in urbanised areas. These issues, in turn, are analysed in terms of developing algorithms to reduce congestion and the negative impact on the environment when searching for parking spaces [9], [10]. The need to optimize parking or

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navigation systems is also indicated in [11] and [12]. Within the scope of ISRB, researchers have also investigated the impact of vacancy search on network congestion or travel times [13]. On the other hand, there exist transport orders which require special conditions for parking, with locations of their execution not being accidental. Such parking also frequently requires identification before the beginning of the trip. Such orders include the transportation of valuable loads (e.g. electronic equipment) [14], transportation of dangerous loads [15], and transportation of oversized loads [16], [17].

The VRP for vehicles requiring specific parking conditions is not only relevant from a logistical point of view. The presence of parkings with defined specifications may both determine the route to a considerable degree, but also condition the completion of the transport task. For example, Ekwall and Lantz estimated in their work [18] that the vast majority of theft incidents (including valuable cargo) occur in unsecured parking lots. In this case, a lack of security means a lack of equipment, including monitoring systems and physical protection. Lizbetin and Bartuska [19] also perceived the unsuitability of parking in the context of abnormal transport. For this transport segment, it was assessed that the issues under study involve not only the lack of equipment, but also the throughput capacity associated with sufficient parking space. As a result, drivers are often forced to seek emergency parking in violation of regulations applicable to driver working time. These aspects exacerbate the risks associated with the transport of abnormal loads, with a clear emphasis on the particularly negative impact on other road users and infrastructure in the process of the entire movement [20]. Furthermore, regulations concerning the transport of hazardous goods also describe specific requirements stipulated for parking spaces [21]. In accordance with these principles, vehicles carrying out these tasks should be parked in such a way as to protect other users from potential damage, and parking should be located at an appropriate distance from the main public roads and residential areas. Based on this information, it can be concluded that the issue of VRPs for vehicles requiring special parking conditions is an appropriate research direction. This may contribute to greater safety of road users, minimisation of the costs of potential incidents, and increasing the chances of successfully completing a transport task. It is noteworthy that Schiffer *et al.* in [8] based on the publications analysed, did not specify any safety criterion in any context of the RIPS problem.

The aim of this study is to develop a model based on VRP, which determines the route prior to the trip from one shipping point to one receiving point for vehicles requiring specific parking conditions, taking into account the aspects considered necessary to capture the essence of the problem:

- parking availability and parking space,
- driver's working time,
- traffic flow,
- equipment of parking lots.

TABLE 1. Comparison of transportation problems in this paper and related articles.

Problem Chosen from	Drivers working time	Parking safety	Parking availability	Parking space	Congestion	Environmental pollution
Our paper	✓	✓	✓	✓	✓	—
[4]	—	—	—	—	✓	—
[9]	—	—	✓	—	✓	—
[10]	—	—	—	—	—	✓
[22]	✓	—	✓	—	—	—
[23]	✓	—	—	—	—	—

The proposed solution combines the above aspects. Routing is carried out on the basis of the algorithm that takes into account all these factors simultaneously. The most similar approaches in the literature are presented in Table 1.

In most cases, the RIPS is analysed from the point of view of one or two aspects. Meanwhile, the authors believe that this problem should be looked at more broadly, at the same time categorizing vehicles and making appropriate calculations from the point of view of the transported cargo.

This article has been organised in the following manner. The subsequent section outlines the requirements associated with the correct identification of vehicles and parking. Its purpose is to carry out a valid assessment of the parking, which will ultimately determine the route of the trip. Next, the theoretical assumptions of the model are presented, taking into account a number of decision variables, constraints, and criterion functions. Then, the results from the implementation of the solution for a real national road network of Mazovia Province (Poland) were presented, based on the implementation of the solution using the Neo4j technology. At the end of the study, conclusions were formulated, and further research directions were defined.

II. FORMULATIONS AND PROBLEM DESCRIPTION

The general characteristics of the problem of routing vehicles requiring special parking conditions, analysed in the work, are as follows:

- The object of investigation is a vehicle with adopted relevant parameters, which is to move from point A to point B. The parameters of this vehicle determine the technical possibility of parking in a designated space or determine the required level of security for them.
- The route of the vehicle is determined on the basis of the knowledge of the road network at a given moment prior to the trip.
- The structure of the road network is mirrored in such a way that the selected fine search algorithm can be applied to it.

- The parking is analysed only in terms of the parameters described in the study, based on the data available before the trip.
- The final choice of the route is made by the carrier, from the point of view of the selected criterion or the evaluation of several of them.

A. VEHICLE

At first, it was decided to use the symbol c, $c \in C$ to reproduce the research object – a vehicle with cargo requiring special parking conditions. In order to determine the relevant parameters of loaded vehicles, relevant literature was analysed. The aspects related to all vehicles were distinguished from the aspects related to the specificity of individual transports. Regardless of the type of cargo transported, the factor determining the possibility of parking is the dimensions of the vehicle. Mikusova and Abdunazarov in [24] modelled the movement of vehicles in the parking space in order to estimate the space required for manoeuvring. In their study, several parameters allowing this assessment to be made were distinguished, and from the point of view of this article, the key parameters will be: $c_{wth}(c)$ vehicle width – taking into account the width of the cargo and $c_{len}(c)$ the length of the vehicle – taking into account the length of the cargo. These dimensions will be necessary to assess the possibility of parking in a given place and whether it will be possible to use emergency spaces such as lay-bys along the road.

For proper analysis of the issue in question, it is important to consider the issue of the driver's working time, which is governed by relevant regulations. These regulations allow for, among others, working in tandem, enabling the implementation of a transport task by a multi-person crew (usually two). In the literature, one can find items analysing VRP from the point of view of the driver's working time [22], [23], [25] and describing the advantages of working in tandem [26], [27].

From the point of view of determining the route for specified parking, it is important to determine whether the vehicle transports hazardous materials. Official documents [28] clearly indicate the need to adapt parking lots to this type of cargo. Therefore, a binary parameter was adopted in the study $c_{haz}(c)$ specifying whether the vehicle transports hazardous materials ($c_{haz}(c) = 1$).

In [29], the European Parliament stated in its report that the percentage of the thefts of cargo from vehicles reached 63%, and the thefts of a vehicle along with its cargo were estimated at 14%. In addition, it was estimated that 67% of the stolen goods could be classified as electronic equipment. In addition, the report indicates that a loss of at least €150,000 represents almost 83% of the total loss suffered due to theft. It is worth emphasizing that these incidents accounted for only 15% of all events. Knowing that the most valuable goods constitute the largest part of the total loss and that it may be related to the type of cargo transported (many relatively small items of high value), an additional parameter was distinguished $c_{val}(c)$ ($c_{val}(c) = 0$ the value of the cargo exceeds €150,000, otherwise $c_{val}(c) = 1$).

B. ROAD NETWORK

The road network proposed in this study is a continuation of studies related to VRPs, based on the most widely described node-based approach [8]. The original solutions in this convention, with an approach to the RIPS problem, were presented, among others, by Rothenbächer, Drexl and Irnich in [30], Yavuz in [31] and Hiermann *et al.* in [32] optimizing financial, ecological and organizational aspects.

In this study, a graph was used to map the road network. This approach is widely discussed in the literature [33]–[35] as an example of describing infrastructure elements and the dependencies between them in order to model real problems and develop solutions which are applicable in practice. The study presents the structure of the road network in the form of a graph: $GP = \langle VP, LP \rangle$($VP$ – a set of road network node numbers, $v, v' \in VP$, LP – a set of road sections (graph arcs)), where $VP = \{v : v = 1, \ldots, v', \ldots, V\}$ (V is the number of vertices in the graph) and $LP = \{(v, v') : (v, v') \in VP \times VP, v \neq v'\}$ [36].

The mapped structure of the road network (graph) contains key elements (vertices) from the point of view of cargo transportation. These are: the cargo shipping point / entry into the transport network, $v \in N$; cargo receiving point / exit from the transport network, $v \in O$; road network node – road intersection or place of change in the technical parameters of a road section, $v \in S$; parkings $v \in P$.

The sets N, O, P, S are disjoint pairs $VP = N \cup O \cup S \cup P$. The proposed diagram of the road network is presented in Fig. 1.

Specific connections exist between individual graph vertices (nodes) which determine the existence of a road connection between these nodes. Direct road connections are included in the set LP, $\{LP = (v, v') : \beta(v, v') = 1, v, v' \in VP \wedge v \neq v'\}$, where $\beta(v, v') = 1$ defines direct connections between nodes v, v'. Otherwise $\beta(v, v') = 0$.

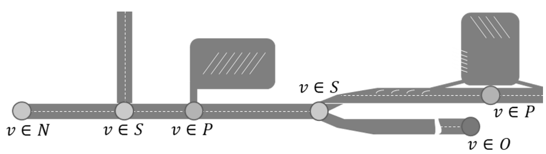

FIGURE 1. Road network diagram.

For the purposes of this study, it was determined that the transport service of an abnormal vehicle between shipping point n and receiving point o is described by a set of transport services defined as ordered pairs (n, o).

The route of the abnormal vehicle in the graph VP between the distinguished vertices (nodes) having numbers n and o was defined as $d(n, o)$ being a finite sequence of the form:

$$d(n, o) = \langle (v_1^p, v_1^k), (v_2^p, \ldots), \ldots, (v_z^p, v_z^k), (v_{z+1}^p, \ldots), \ldots, (v_Z^p, v_Z^k) \rangle \quad (1)$$

where:

- $z-$ subsequent z-th element of the sequence,

- v_z^p – starting node of the z-th arc (z-th element of the sequence) belonging to the route, such that $v_z^p \in VP$
- v_z^k – end node of the z-th arc (z-th element of the sequence) belonging to the route, such that $v_z^k \in VP$
- Z – number of route arcs (sequence elements), where $z \in \{1, \ldots, Z\}$.

A transport network allows for travelling along more than one route between nodes n and o, with one vehicle allowed to travel only once through each node. A single path connecting the vertices (n, o) is marked with the index j. The route j between the vertices (n, o) can be conventionally written as a sequence of consecutively occurring nodes, $d^{j,no} =< n, \ldots, v, \ldots, v', \ldots, o >$ where $d^{j,no} \in J^{no}$ - set of possible routes.

The proposed solution requires consideration of the passage of time. For this reason, the day was divided into segments of a fixed time length – one minute and these were numbered with the indices t, $T = \{1, 2, \ldots, t, \ldots, 1440\}$.

To correctly model the structure reflecting the essence of the problem, the properties of the real road infrastructure should be mapped, and appropriate parameters should be assigned to the arcs. For the purposes of this study, it was considered that these parameters are as follows:

- road type (class),
- road traffic intensity coefficient,
- link length.

The road type will allow for choosing the route for road sections with higher technical requirements, which is crucial in, among others, the transport of abnormal loads. A higher road class also means the possibility of travelling at a higher speed permitted by law, and thus a longer distance covered in a time interval. Therefore, a set of types (classes) of R transport connections was defined, $r_{type} \in R$ the number of which will result from the provisions provided for in the relevant legal acts and will be related to the average speed achieved by the vehicle in the transport connection. The impact of the phenomenon of congestion on vehicles in the transport industry has been described multiple times. On the example of the USA Hooper in [37] shows that this phenomenon generates significant losses and points to specific data emphasizing delay time or a lower average speed of the trip. From the point of view of the problem analysed in this work, congestion may prevent a vehicle from reaching the parking in the previously adopted time interval, which may lead to breach of the regulations or a significant reduction in the level of security. Therefore, the following parameters were defined: $t_{min}(v, v)$, interpreted as the minimum travel time for the connection (v, v'), taking into consideration road traffic regulations, vehicle and load properties, and $t_{avg}(v, v')$ interpreted as the average travel time at a given moment for a connection, (v, v') taking into consideration the current traffic volume.

In this study, it was assumed that the traffic volume coefficient ∂_c will be the ratio of the average travel time at a given moment between the node v and the node v' to the minimum travel time between these nodes, which must be greater than or equal to 1.

$$\partial_c(v, v') = \frac{t_{avg}(v, v')}{t_{min}(v, v')} \geq 1, \quad \forall (v, v') \in LP \tag{2}$$

Estimating this coefficient should include an analysis of the traffic volume for individual arcs at specific time intervals, taking into account the day of the week, weather conditions and the analysis of the most up-to-date traffic situation. Knowledge of the length of the connection will reflect the coefficient $\partial_c(v,v')$ for the actual distance between two road nodes $l(v, v')$ in relation to the length of the entire route.

C. PARKINGS

From the point of view of the analysed issue, the key point for the proposed type of VRP is parking and its characteristics. There are many items in the literature that assess the capabilities of parking. Several areas subjected to analysis are as follows:

- security of:
  - cargo [14], [18], [21], [38]–[41],
  - people [14], [18], [21], [38], [40]–[42],
- driver ergonomics [38], [43],
- capacity:
  - related to the demand [38], [43]–[47],
  - related to technical aspects [17], [19], [24], [48], [49].

Based on of these publications, important parameters that will determine the indication of stops at specific parking lots and ultimately affect the trip route were specified. The scheme of parking with the elements listed is shown in Fig. 2.

The parking parameters distinguished for the purposes of the work are as follows:

p_{slo} – number of parking slots for trucks,
p_{occ} – average occupancy of the truck parking lot at the time t,
p_{spa} – area of a single truck parking space,
p_{haz} – number of parking spaces for vehicles with hazardous cargo,
p_{abn} – free space to be used by an abnormal vehicle,

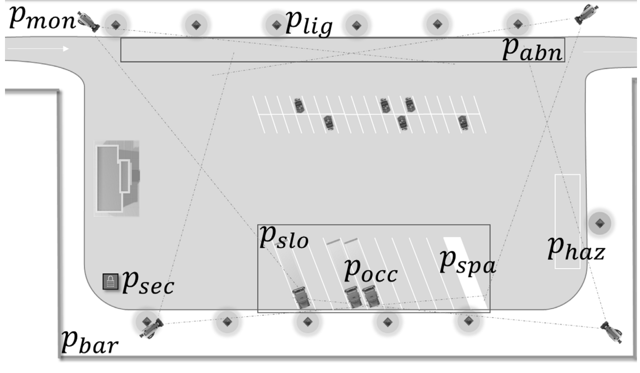

FIGURE 2. Parking diagram.

p_{sec} – presence of security personnel,
p_{mon} – presence of monitoring,
p_{bar} – presence of barriers,
p_{lig} – presence of lighting.

The number of spaces for trucks (Fig. 2 (p_{slo})) is crucial for the driver to execute a transportation task, regardless of its nature. Gopalakrishnan *et al.* in [49], Lizbetin and Bartuska in [19], Carrese *et al.* [39], Mikusova and Abdunazarov in [24] and Gnap and Kubíková in [44] indicated the problem of an insufficient number of spaces ensuring stops (including daily rests), which forces truck drivers to stop in disallowed places or increase traffic congestion during the search for optional parking options. Another study addressed the problem of the unavailability of parking during rush hours, highlighting the negative impact on the transport system and its surroundings [43]. On the other hand Fleger *et al.* in [38] assessed in their study that drivers rarely find space in dedicated parking lots. The growth in demand for truck parking spaces in the USA has been 2.7 percentage points per year, compared to the estimated growth rate of these parking spaces at approximately 1 percentage point per year. Using this item, TRB in [47] evaluated the factor of demand for parking spaces in the USA, which indicated a clear shortage of spaces in 12 of the 49 analysed states. Thus, it should be mentioned that for public parking spaces only, a shortage of spaces occurred in as many as 35 states. In this study, the parameter reflecting the number of parking spaces for trucks is expressed as $p_{slo}(v)$.

The issue of the difference in supply and demand for parking spaces (Fig. 2 (p_{occ})) has been the starting point for many research papers. In one of them, [48] signalled the necessity of developing intelligent systems for guiding parking spaces based on the knowledge of the actual parking lot occupancy. The possibility of calculating this parameter exists owing to the existing systems and further work is observed in this area [10], [12], [50]. Based on the research by Fleger *et al.* [38], it was found that in public parking spaces, drivers always or often find a free space in only 11% of cases. This rate was 34% for commercial parking spaces. Martin and Shaheen in [46] estimated that prior knowledge of parking lot occupancy would be useful for drivers in up to 81% of cases. They obtained similar results as Morris *et al.* in [51], which was the point of departure for them to develop a system for identifying free parking spaces for trucks. Therefore, the study also included the parameter of an average parking lot occupation for vehicles $P_{occ}(v)$. This parameter will be a 24-element set, reflecting an average parking lot occupancy for 24 time intervals p_{occ_i}, resulting from the division of a day into 24 equal parts - $P_{occ}(v) = \langle p_{occ_1}, \ldots, p_{occ24} \rangle$ for $p_{occ_1}, \ldots, p_{occ_{24}} \in \langle 0, 1 \rangle$, where p_{occ_1} is the interval describing the average occupancy between 00:00 and 01:00, etc., and this parameter will take the value 1 if all parking spaces are occupied during the mentioned hours.

Mikusova and Abdunazarov [24] described parking lot design standards and outlined the dimensions intended for a single truck (Fig. 2 (p_{spa})). This entry stresses that the average dimensions adopted in the calculation of the parking area are determined to be 40 m^2, while the actual area should be almost twice as large. Moreover, the paper also specified that for large trucks, this space should have dimensions of at least 41 meters in length and 5.2 meters in width. For the purposes of this study, it was assumed that the area of a single place for a truck in a parking area will reflect: $p_{spa_w}(v)$ and $p_{spa_l}(v)$ –width and length of the free area to be used by a truck.

In view of the currently applicable rules and regulations in the European Union, vehicles with hazardous cargo are obliged to stop in places with defined technical specifications (Fig. 2 (p_{haz})). Caro-Vela *et al.* in their work [15], define the methodology for organizing a network of parkings for this type of vehicle in Spain. In the same literature entry, they also highlight the criteria which condition the possibility of a vehicle carrying hazardous cargo to stop at a given location. In practice, however, these conditions are strictly defined by a series of internal documents that regulate these issues. For example the Polish Ministry of Internal Affairs in [52] has set out requirements for parking lots for hazardous cargo, including the number and surface area of the parking spaces, as well as adequate spacing in relation to critical points, that is residential buildings or other vehicles. Therefore, it was determined that the parameter relating to the number of parking places for vehicles with dangerous cargo took the form $p_{haz}(v)$.

Often, the specific nature of abnormal vehicles is linked to the problematic dimensions of width and length, which means that the parking problem should be viewed in a way being differently from the usually accepted one. As mentioned earlier, parking spaces for trucks usually do not exceed 40 m^2, and the organization of traffic in the parking lot and the placement of its elements result from these dimensions. Nonetheless, a parking lot sometimes has a bay in the main lane or an area whose development does not significantly affect other participants (Fig. 2 (p_{abn})). This area can be used for an abnormal vehicle, and it should be positioned in such a way as to minimize the need for manoeuvres (turning, reversing). This need arises mainly from the transport of long loads. Vehicles with such loads often use an exit ramp and then position themselves extremely close to the left curb (for right-hand traffic) in the parking space without preventing the manoeuvre of passing and without performing any additional manoeuvres. A wide vehicle, on the other hand, does not usually have to use this type of space as it can, for example, occupy 2-3 truck parking spaces. The free area available for use was expressed in the form of parameters: $p_{abn_w}(v)$ -the width of the free area available for use to an abnormal vehicle, $p_{abn_l}(v)$-the length of the free area available for use to an abnormal vehicle. It often occurs that such a parking area functions not as a full-fledged parking, but as a bay next to the roadway, and it is a common solution in urban areas. Marshall *et al.* in [53] describe this aspect, drawing attention to its usefulness from the perspective of land-use and even from the perspective of increasing the level of security for traffic users. However, there is no consensus among researchers on the final evaluation of this issue [54], [55], and both viewpoints are described by Guo *et al.* in [56].

The presence of security personnel at the parking lot (Fig. 2 (p_{sec})) was addressed in the work by Carrese *et al.* [39], who established that a proper security system is the most desirable service in parking. The presence of physical protection caused the quality of this protection to become *good* in light of the adopted criteria. The parameter reflecting the presence of security personnel is expressed in the form of a binary parameter $p_{sec}(v)$.

In the literature, the issue of the presence of monitoring at parking (Fig. 2 (p_{mon})) has been analysed many times, also in terms of offences targeting a motor vehicle or its equipment (load). Welsh and Farrington stated in their work [57] that CCTV was the most effective precisely in this respect, which was later confirmed in other works [39], [58]. In connection with this, it was determined that the parameter relating to the presence of monitoring would take the form of a binary parameter $p_{mon}(v)$.

The presence of a fence in a parking space (Fig. 2 (p_{bar})) was mentioned in the reports [28], [41] which stated that the presence of barriers surrounding parking lots is of key importance from the point of view of security. In addition, Carrese *et al.* in [39] determined in their work that the presence of a fence in an illuminated location makes the protection of this place qualifiable as *sufficient*. In this study, this parameter takes the form of a binary parameter $p_{bar}(v)$.

In the literature, attention has been paid to the issue of parking lot lighting (Fig. 2 (p_{lig})) and the extent to which it affects the security of drivers and cargo. For example, Rea *et al.* in [59] analysed the effect of the type of lighting on the visibility at parkings and on the sense of security. Their research shows that in most cases unobstructed driving is possible, and people moving in a parking lot are easily visible. Both the reports [40], [41], [47] and the guidelines describing standards and good practices in the design of parking lots [60] emphasize the importance of this aspect. However, the presence of lighting alone, as an element intended to increase the level of security, is insufficient, which is noted, among others, by Carrese *et al.* in [39]. The parameter describing the presence of lighting at parking is described as $p_{lig}(v)$.

Ultimately, the parameters $p_{sec}(v)$, $p_{mon}(v)$, $p_{bar}(v)$ and $p_{lig}(v)$ will determine the general level of security $s(v) \in \langle 0, 1\rangle$ at individual parkings, and the method of its determination is presented later in this work. The technical possibility of having a stop is reflected by the parameter $\gamma(v, c)$ ($\gamma(v, c) = 1$ the vehicle can stop at a parking.

D. DRIVING TIME RESTRICTIONS

Research shows that in the vast majority of cases, the stops made by professional drivers are forced by legal aspects [39]. The issues related to drivers' working time are described in the relevant legal acts, specific to individual countries or international organizations [61], [62]. An appropriate assessment related to the parking, performed sufficiently early, minimizes the probability of the necessity to extend the driver's working time. This time may be extended in order to find a suitable parking lot, which additionally burdens the driver and has a negative impact on security, which is mentioned in many contemporary works [63]–[65]. By analysing the above-mentioned regulations, it is possible to identify some common features on the basis of which this aspect can be modelled in this work. The driver's work schedule consists of the following elements such as:

- t_{st_i} – Single driving time, which cannot be longer than the value t_s specified in the regulations. It is followed by a break in driving s_{d_i}.
- t_{dt_i} – The daily driving time, which cannot be longer than the value t_d specified in the regulations. The daily driving time usually consists of 2 or 3 driving periods t_{st_i}, depending on the adopted strategy. They are followed by the so-called daily rest s_{n_i}.
- t_{wt_i} – Weekly driving time, which cannot be longer than the value t_w specified in the regulations. It is followed by the so-called weekly rest s_{w_i}.

Due to the fact that the travel time t_t covering one transport task between the shipping point and the receiving point rarely exceeds the weekly driving time allotment, limits of two-week and longer ones were not considered in this work.

The aspect of the minimum length of individual stops is discussed in the regulations, but ultimately its length will result from the driver's needs, although in practice it is aimed at minimizing it. In order to locate this aspect in the model, the parameter $t_r(d^{j,no}, v, c)$ is interpreted as the stop time at the node $v \in P$, if it has been selected as the parking for the vehicle c traveling along the route number j in the service (n, o). The value $t_r(d^{j,no}, v, c)$ will ultimately depend on the type of rest at the node $v \in P$ and the convention adopted by the carrier in the light of applicable regulations. The general diagram of stops is presented in Fig. 3 and shows an example movement between points n and o in time t_t, consisting of i individual driving times t_{st_i}.

E. DECISION VARIABLES

The parking lots assigning method for vehicles requiring specific parking conditions, proposed in the work, can be considered in terms of optimizing driver working hours and as well as increasing the level of safety by choosing appropriate parking to stop. Meeting these assumptions is possible by solving the optimization task, the formula of which will correspond to the decision-making situation under consideration. Therefore, the following types of decision variables were defined:

1. binary – $y((v, v'), c)$
   The assumption of value 1 by this variable means that (v, v') a vehicle c is traveling through the transport connection. Otherwise $y\left(\left(v, v'\right), c\right) = 0$.
2. binary – $u(v, c, t)$
   The assumption of value 1 by this variable means that through the node v in time t a vehicle c is traveling. Otherwise $u(v, c, t) = 0$.

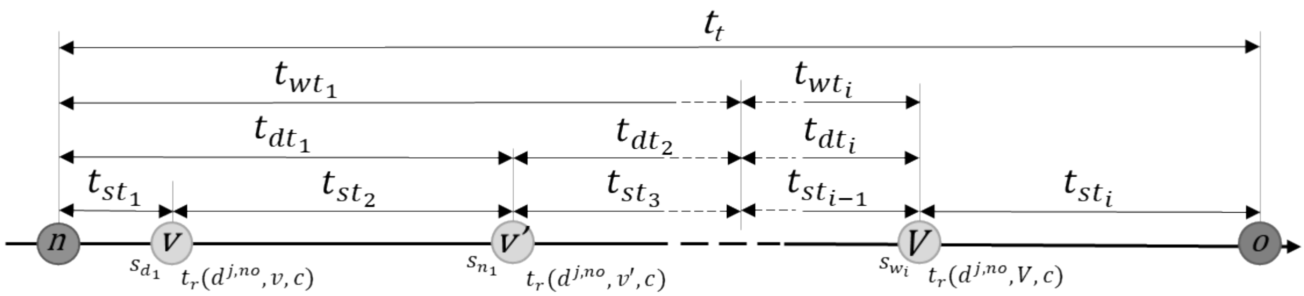

FIGURE 3. **General diagram of stops resulting from the regulations on drivers' working time.**

3. real - $\omega\left(\left(v, v'\right), r_{type}, c\right)$
$\omega\left(\left(v, v'\right), r_{type}, c\right)$ - the speed of the vehicle c, traveling through the transport connection of the $\left(v, v'\right)$ type r_{type}.

F. OPTIMIZATION MODELS

In this work optimization will be carried out with regard to:

- minimizing travel time:

$$t_t = \sum\nolimits_{v\epsilon P} t_r(d^{j,no}, v, c) + \sum_{(v,v')\in d^{j,no}} \frac{l\left(v, v'\right)}{\omega\left((v, v'), r_{type}, c\right)} \cdot \partial_c(v, v') \cdot y((v, v'), c) \rightarrow \min, \forall (n, o) \in E, \ \forall d^{j,no} \in J^{no}, \ \forall c \in C \quad (3)$$

- minimizing the congestion:

$$\partial = \frac{\sum_{(v,v')\in d^{j,no}} l\left(v, v'\right) \cdot \partial_c(v, v')}{\sum_{(v,v')\in d^{j,no}} l\left(v, v'\right)} \cdot y((v, v), c) \rightarrow \min, \forall (n, o) \in E, \ \forall d^{j,no} \in J^{no}, \ \forall c \in C \quad (4)$$

- maximizing the security of parkings along the route:

$$\mu = \frac{\sum_{\substack{v\in P \\ \gamma(v,c)=1}} s(v) \cdot u(v, c, t)}{\sum_{\substack{v\in P \\ \gamma(v,c)=1}} u(v, c, t)} \rightarrow \max, \forall (n, o) \in E, \ \forall d^{j,no} \in J^{no}, \ \forall c \in C, \ \forall t \in T \quad (5)$$

- minimizing the load on parking spaces along the route:

$$\rho = \frac{\sum_{\substack{v\in P \\ \gamma(v,c)=1}} p_{occ_i} \cdot p_{slo}(v) \cdot u(v, c, t)}{\sum_{\substack{v\in P \\ \gamma(v,c)=1}} p_{slo}(v)} \rightarrow \min, \ p_{occ_i} \in P(v), \ \forall (n, o) \in E, \ \forall d^{j,no} \in J^{no}, \ \forall c \in C, \ \forall t \in T \quad (6)$$

- maximizing the number of free parking spaces per a parking along the route:

$$\tau = \frac{\sum_{\substack{v\in P \\ \gamma(v,c)=1}} p_{slo}(v) \cdot \left(1 - p_{occ_i}\right) \cdot u(v, c, t)}{\sum_{\substack{v\in W \\ \gamma(v,c)=1}} u(v, c, t)} \rightarrow \max, \forall (n, o) \in E, \ \forall d^{j,no} \in J^{no}, \ \forall c \in C, \ \forall t \in T \quad (7)$$

G. CONSTRAINTS

The following constraints were distinguished in the proposed model, related to:

1. Maximum travel time:

$$t_t \le t_{max}(c, (n, o)), \quad (8)$$

where:

$$t_t = \sum_{v\epsilon P} t_r\left(d^{j,no}, v, c\right) + \sum_{(v,v')\in d^{j,no}} \frac{l\left(v, v'\right)}{\omega\left(\left(v, v'\right), r_{type}, c\right)} \cdot y((v, v'), c) \quad (9)$$

$t_{max}(c, (n, o))$- maximum travel time specified by the carrier for a vehicle ctv moving in the service $n - o$.

2. Selection of one route:

$$\sum\nolimits_{d^{j,no}\in J^{no}} \prod\nolimits_{\left(v,v'\right)\in d^{j,no}} \cdot y((v, v'), c) = 1, \forall (n, o) \in E, \ \forall c \in C \quad (10)$$

3. Driver's working time:

$$t_t = \sum\nolimits_{i=1} t_{st_i}, \quad \forall d^{j,no} \in J^{no}, \ \forall c \in C \quad (11)$$

where:

$$t_{st_i} = \sum\nolimits_{(v,v')\in d^{j,no}} \frac{l(v, v')}{\omega((v, v'), r_{type}, c)} \cdot \partial_c(v, v') \cdot y((v, v'), c) \le t_s \quad (12)$$

for consecutively appearing nodes (v_1^p, v_1^k), $(v_2^p, \ldots)$, ..., $(\ldots, v_{z-1}^k)$, (v_z^p, v_z^k) belonging to the route:

$d(n, o) = \langle(v_1^p, v_1^k),(v_2^p, \ldots), \ldots,$
$(\ldots, v_{z-1}^k), (v_z^p, v_z^k), (v_{z+1}^p, \ldots), \ldots, (v_Z^p, v_Z^k)\rangle,$
whereby if:

- $t_s \le t_t \le t_d$ the vehicle c must each time stop for the time specified by the stop type s_{d_i}, before the elapse of time t_s at the parking meeting the specified requirements, and $t_{st_i} \rightarrow t_s$;
- $t_d \le t_t \le t_w$ then the vehicle c must each time stop for the time specified by the stop type s_n, before the elapse of time t_d at a parking meeting the specified

requirements and $\sum_{i=1} t_{st_i} \rightarrow t_d$ for t_{st_i} not separated from each other by a stop other than s_{d_i};

- $t_w \leq t_t$ the vehicle tvc must always stop for the time specified by the type of stop s_w, before the expiry of the time t_w at the parking meeting the specified requirements and $\sum\sum_{i=1} t_{st_i} \rightarrow t_w$ for t_{st_i} not separated from each other by a stop other than s_{n_i} or s_{d_i}.

4. Possibility of making a stop:

$$\bigvee_{v\in P} \gamma\,(v, c) = 1, \quad \forall d^{j,no} \in J^{no},\ \forall c \in C \tag{13}$$

for each part of the route travelled in a single period t_{st_i}, whereby $\gamma\,(v, c) = 1$ for:

- vehicle dimensions, when:

$$c_{wth}(c) < p_{abn_w}(v) \wedge c_{len}(c) < p_{abn_l}(v) \text{ for } c_{wth}(c) < p_{spa_w}(v) \vee c_{len}(c) < p_{spa_l}(v), \quad \forall c \in C, \forall v \in P \tag{14}$$

- the presence of dangerous cargo when:

$$c_{haz}(c) = 0 \vee c_{haz}(c) = 1 \wedge p_{haz}(v) < 0, \quad \forall c \in C,\ \forall v \in P \tag{15}$$

- parking occupancy at a given moment when:

$$p_{occ_i} < 0.85, p_{occ_i} \in P_{occ}(v),\ \forall v \in P,\ \forall t \in T \tag{16}$$

- safety of the parking when:

$$c_{val}(c) = 0 \vee c_{val}(c) = 1 \wedge s(v) \geq 0.75, \quad \forall c \in C,\ \forall v \in P \tag{17}$$

III. SOLUTION METHODS

The basic procedure being part of the developed solution is the basal algorithm which performs the operation of determining the route between the points of shipping and receiving cargo. These routes will be analysed successively from the route consisting of the smallest number of nodes to the moment when the next instance reaches the travel time greater than the declared maximum time t_{max}. This approach focuses not on the routing process itself, but on the analysis and evaluation of the route returned by any implemented search algorithm from the point of view of stop possibility. Thanks to this, it is possible to use many available solutions, depending on the needs stemming from, among others, computational complexity. The need to perform specific procedures on a multi-element set $J^{n,o}$ is important from the point of view of the specificity of transporting cargoes specified in this work. It may turn out that it is more desirable to make a double stop on a route with a longer travel time, where places with a high security parameter $s(v)$ occur, than on a shorter route with one stop, where sufficient equipment is lacking. Algorithm 1, which is performing the route calculation procedure, its evaluation and further assignment is presented on the next page.

The procedure performed for a single iteration of the while loop creates the shortest path in the analysed road network between the shipping and receiving points, based on the selected search algorithm. Subsequently travel times between individual road sections (v, v') will be assigned to initially declared 0 values for individual travel times $t_{st_i}, t_{dt_i}, t_{wt_i}$. When the value of a single, daily or weekly driving time is exceeded, it is necessary to initiate Algorithm 2, which will assess the possibility of a parking.

Regardless of the parking selected in this procedure, it will be necessary to reset the specified driving time and reduce the remaining driving times so that they take into account going backwards in order to find the mentioned location. In addition, the algorithm must add to the travel time t_t the duration of the stop t_r and resume the procedure for the route starting from this parking. These actions are repeated each time if the values $t_{st_i}, t_{dt_i}, t_{wt_i}$ exceed the values t_s, t_d, t_w specified in the regulations. It may happen that a situation occurs in which the procedure contained in the loop for does not return a parking, which is tantamount to the fact that the vehicle is not able to reach the parking within the time required by the regulations and in this situation, they will be violated. When such a condition occurs, Algorithm 1 will discard such a route and load another one to conduct its analysis. The routes for which the verifying procedures returned correct results are added to the set $J^{n,o}$, the elements of which are finally returned and assessed against the selected criteria.

The key element in the developed method is the algorithm that selects parking depending on the characteristics of the vehicle and the specificity of this location. As mentioned previously, parking may be determined by technical factors or security-related aspects. In the latter case, it is necessary to classify these places properly. For this purpose, five security categories were defined, related to the value of the parameter $s(v)$, assuming values from 0 (no security measures) to 1 (all security measures). The following literature items were used to assess the level of security [39], [57], [58], and the table presenting the different categories of parking places, depending on the presence of individual elements, is presented in Fig. 4.

When assessing the security of the parking, a distinction was made between passive and active security elements. The level of security is mainly influenced by the presence of a CCTV system and security personnel. The presence of any of these elements will cause the security level $s(v)$ to assume a value of not less than 0.5, and at least 0.75 if they occur jointly. Furthermore, the use of any passive and active security element indicates security level of 0.75. The most desirable security level of 1 will occur with full active protection with at least one passive protection element. Algorithm 2, in the case of valuable ones, will search the route in terms of the presence of parkings at the level of at least 0.75 and will aim to maximize the security level of all places on this route (in the event of a change in the driving schedule as a result of unforeseen events). The procedure performed for a single iteration of the while loop will create the shortest path in the analysed road network between the shipping and receiving points, based on the selected search algorithm. Subsequently

Algorithm 1 Calculating Stops for Set of Routes

Input: set of vehicles (C), set of loading points (N), set of unloading points (O), set of parkings (P), set of transport nodes (S), set of roads (LP), maximum travel time (t_{max}), driving time restriction params (t_s, t_d, t_w), empty set of routes with assigned stops ($J^{n,o}$), starting time (t_0)
Output: Possible routes with assigned stops and general params
Create the new vehicle $c \in C$
Specify start and end points ($v \in N$, $v \in O$)
Set total time of travel as $t_t = 0$
while $t_t < t_{max}$ (8) **do**
  Compute the shortest path sequence $d^{j,no}$ between n *and* o with longer period of time than t_t
  Set particular types of travel time as $t_{st_i}, t_{dt_i}, t_{wt_i} = 0$
  Create an empty set for checked nodes (F)
  Create an empty set for capable parkings on route (L)
  Create a variable $r = d^{j,no}$
  while number of elements of the set $F <$ number of objects in the primary sequence $d^{j,no}$ **do**
   for every single road between v and v' in set assigned to variable r **do**
    if $t_{st_i} < t_s$ *and* $dt_{dt_i} < t_d$ *and* $t_{wt_i} < t_w$ **then**
      Add time of travel between *vand* v' (based on data from set LP) to t_{st_i}, t_{dt_i}, t_{wt_i} and t_t
      Add checked node ($v, v' \in N \cup O \cup S \cup P$) to set F
    else
      Assign the capable parking from set P (Algorithm 2)
      if Algorithm 2 returned a parking **then**
        Determine parking as stop on route, assess a type and add it to set L
        Create a set with nodes preceding returned parking (R)
        Change t_{st_i}, t_{dt_i}, t_{wt_i} and t_t values in relation to type of rest (11 - 12), parking time (t_r) and going back in time by Algorithm 2
        Overwrite set F as set R
        Reduce the primary sequence $d^{j,no}$ by set R and assign it to variable r
        break
      else
        Determine the $d^{j,no}$ as invalid
        break
 if it was possible to determine valid parkings for $d^{j,no}$ route **then**
    Add $d^{j,no}$ to set $J^{n,o}$
 else
    continue
 Assess routes from set $J^{n,o}$ based on optimization models (3 - 7) and data from set LP
 Return routes from set $J^{n,o}$ with params

travel times between individual road sections (v, v') will be assigned to initially declared 0 values for individual travel times $t_{st_i}, t_{dt_i}, t_{wt_i}$. The procedure performed for a single iteration of the while loop creates the shortest path in the analysed road network between the shipping and receiving points, based on the selected search algorithm. Subsequently travel times between individual road sections (v, v') will be assigned to initially declared 0 values for individual travel times $t_{st_i}, t_{dt_i}, t_{wt_i}$. When the value of a single, daily or weekly driving time is exceeded, it is necessary to initiate Algorithm 2, which will assess the possibility of a parking. Regardless of the parking selected in this procedure, it will be necessary to reset the specified driving time and reduce

The selection of a parking on the route is based on the checking procedure. Depending on the specificity of the vehicle and the estimated parking time, the algorithm identifies the selected location and assesses its suitability from the point of view of the preset criteria. This algorithm is presented below (Algorithm 2).

The Algorithm 2 described above will be started in the case of exceeding the permissible parameter values t_s, t_d, t_w. The algorithm checks individual nodes in reverse order, starting from the initial node of the road section where the regulations on drivers' working time would be violated. In addition, it also reduces the initial time t_s by the travel time along individual road sections. When we come across the parking $\in$ vP, it will be checked. It will begin with determining whether for the reduced time t_s, which is the approximate time of arrival to the parking place, the parameter of its occupancy is satisfactory. If this condition is met, the algorithm will

Algorithm 2 Parking to Route Assignment

Input: parameters of vehicle ($c_{wth}, c_{len}, c_{haz}, c_{val}$), set of parkings ($P$), set of checked nodes (F), set of roads (LP), time from start of travel to last node in set F (t_s)

Output: parking with desired characteristics

```
Create a variable x = set C with elements in reversed order
Create a variable s for determined parking
for every node v in set x do
    Reduce t_s time of travel between node v and subsequent node (calculated on the basis of data from set LP)
    if ∈ vP then
        if the parking occupancy is acceptable for estimated time of stop t_s (16) then
            if the vehicle can fit in single parking space or can fit in additional parking zone (14)
                if the vehicle transport a valuable cargo (c_val = 1) then
                    if a protection level of the parking ≥ 0.75 then
                        Determine a parking as the place for stop on route and assign it to variable s
                        break
                    else
                        continue
                else if the vehicle transport a hazardous cargo (c_haz = 1) then
                    if the parking has a parking space for vehicles with hazardous cargo (15) then
                        if a protection level of the parking ≥ 0.75 then
                            Determine a parking as the place for stop on route and assign it to variable s
                            break
                        else
                            continue
                    else
                        continue
                else
                    Determine a parking as the place for stop on route and assign it to variable s
                    break
            else
                continue
        else
            continue
    else
        continue
if variable s has the assigned parking then
    Return the parking
else
    Return the information that a parking cannot be determined
```

proceed to determine whether the size of the vehicle allows it to stop at the parking place (16). In a situation where it is possible, there will appear procedures to check whether the transported cargo belongs to valuable or hazardous goods (15) and if such a condition occurs, it will check the parking possibilities for $v \in P$. If they are sufficient in the light of the accepted conditions, and if the size of the vehicle does not exceed the size of the available parking space for vehicles not transporting valuable and hazardous cargoes, this space will be defined as a stop on the route and will be assigned to the variable s. Its return will initiate further procedures which constitute Algorithm 1. Failure to meet any of the conditions for Algorithm 2 will result in the analysis of subsequent nodes in the set assigned to the variable x. If none of them is recognized as correct or if there occurs no such node that $v \in P$, then the algorithm will return information that it is not possible to determine the stop.

To illustrate the operation of Algorithms 1 and 2 in figure (Fig. 5) a fragment of an example route between points $(n, o) \in E$ for a vehicle carrying valuable cargo ($c_{val} = 1$) is presented. It has been divided into 15 driving sections, and the total duration of the movement exceeds the value t_w,, therefore it includes all types of stops distinguished in this work. In the route presented in Fig. 5, only such nodes are distinguished that $v \in P$ in order to facilitate analysis. The nodes $v \in S$ are located between the parking nodes and their number and place of occurrence are not important at this moment.

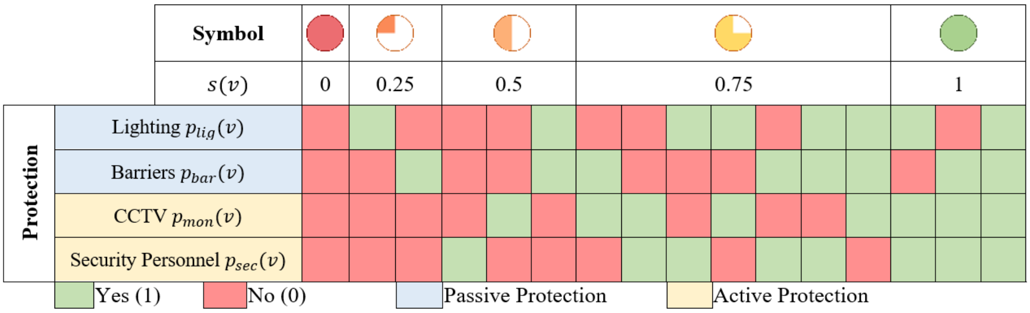

FIGURE 4. Division of parkings with regard to parking security depending on the presence of components.

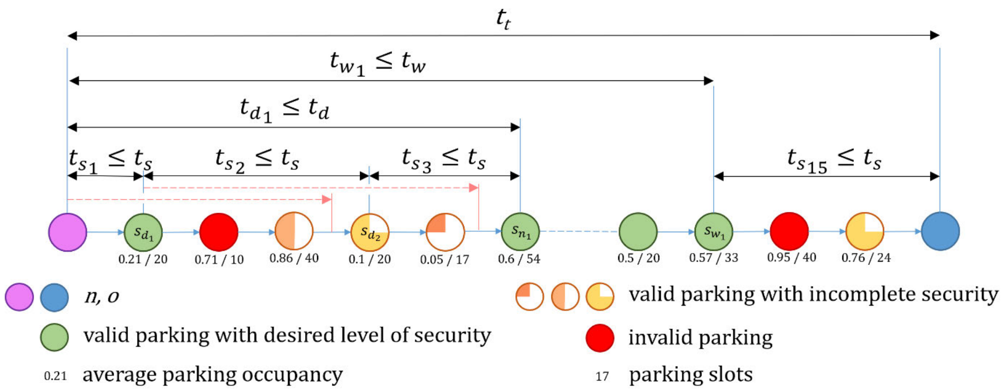

FIGURE 5. An example selection of parking places carried out by Algorithm 2.

Analysing the example in Fig. 5, the vehicle tv after starting the trip, may move past the parking node, for which the occupancy for a given time interval is 0.86. This node was the first to be analysed by the algorithm, but due to the insufficient parameter $s(v) = 0.5$ it had to be rejected. Another node with occupancy of 0.71 was also rejected due to the lack of sufficient parking space, and therefore the algorithm shifted back to the node with occupancy of 0.21. This node met the necessary criteria and, due to the fact that the daily driving time was not exceeded t_d, a driving break was planned in it s_{d_1}. Analogously, during the second driving period, the vehicle c for the duration of time t_s was able to move past the parking node with occupancy of 0.05. This node, being the first to be analysed, did not meet the required security level, therefore a stop s_{d_2} was possible only in the node with occupancy of 0.1. Another node for which the algorithm planned a stop s_{n_1} this time was one with occupancy of 0.6, and the type of stop was forced by the failure to meet the equation $t_{d_1} \leq t_d$. The algorithm proceeded in a similar fashion for the rest of the route.

IV. EXPERIMENTS

The research carried out for the purposes of this article was based on the implementation of the algorithm for the real national road network of Mazovia Province in Poland. The mirrored transport network consisted of 462 transport nodes and 602 transport connections. The structure was built on the basis of the Neo4j platform which allows the creation of graph-based data structures. The database used the resources of a virtual machine in the DigitalOcean cloud storage with the following parameters: Ubuntu 18.04.3 (LTS) x64, 1 x vCPU, 2 GB RAM, and 50 GB disk SSD. The simulations were performed using a proprietary web application built using Python 3, Angular 7 and Java 11 technologies, with Docker responsible for the containerisation of individual services. Fig. 6 presents the layout of the transport network based on an interactive map embedded in the application.

For 113 transport nodes, an exit ramp leading to the parking space was available. The location of the sites and their characteristics were reproduced based on acquired data from the General Directorate for National Roads and Highways and using the Google Maps platform. Fig. 7 presents the location of parking spaces with a mapping of their parking capacity (number of slots for trucks) and security level. Random parameters p_{occ_i} were generated for each of these locations, since there exist no automated parking occupancy monitoring systems of parking spaces in the specified parking places.

For the purposes of this study, three simulations where run for one pair of shipping and receiving nodes. These simulations differed in terms of vehicle type, travel times, and time constraints arising from the driver working time. This study did not refer to the actual values resulting from specific regulations due to the mapping of the transport network for a small area (33 558 km^2). Therefore, these time values were reduced in such a way that the algorithm was able to select parking places of different categories.

In this work, the movement of the vehicle in the southeast direction was assumed, covering the cargo shipping and receiving nodes located in the central part of the analysed area. Their selection is also driven, among other things, by the need to allow the network to be searched in multiple directions. The direction of travel between the mentioned nodes is shown in Fig. 8, which is the section of the map marked by the red frame in Fig. 6.

The presented proposal of a pair of shipping and receiving nodes was also forced by the desire to increase the number of potential parkings along the route. Their grouping is particularly evident in the central part of the analysed area (Fig. 7), which will increase the number of possible options for analysis.

A. SCENARIO 1: A VEHICLE WITH HAZARDOUS CARGO

In the case of a vehicle carrying hazardous cargo, it was assumed that the vehicle would fit into a standard parking space designated for a truck. The special needs of this vehicle are based solely on the presence of hazardous cargo, as it was estimated that only 13 percent of the parking spaces in the analysed network have the capability to secure this type of vehicle. Because the occurrence of such places on the route may be difficult, the time of individual parameters has been extended t_s, t_d, t_w concerning other types of traffic. Other parameters are identified in Table 2.

Given the nature of the transport, the most relevant point in the performance of the algorithm is to simply find a route that ensure the possibility of making a stop. It should be noted here

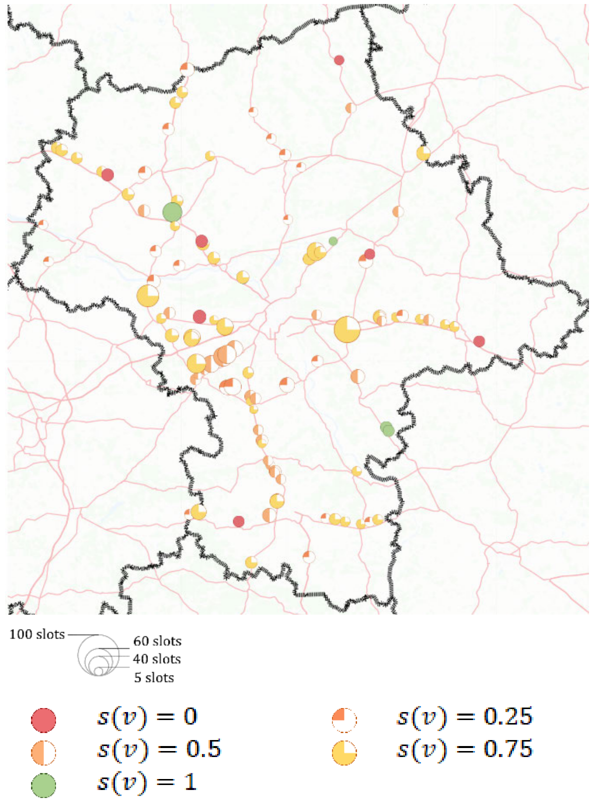

FIGURE 7. The diagram of the location and availability of parking places in the analysed road network.

that the assessment of the route in terms of the criterion of maximizing the number of available spaces (7), considering the parameter of the number of spaces for vehicles with hazardous cargo c_{haz}, may be hampered. This is due to the low number of such spaces at the selected parking locations in the analysed network (typically 1-3). It was also assumed that the occupancy level of parking spaces ρ is also reflected in the amount of space available for vehicles with hazardous cargo.

B. SCENARIO 2: AN ABNORMAL VEHICLE

For a vehicle which exceeds the dimensions specified in the relevant regulations, it was determined that the problem of selecting the route considering parkings will be affected by the length and width parameters of the vehicle. This is because Scenario 2 assumes that a vehicle with a width of 5,000 mm and a length of 40,000 mm significantly exceeds the dimensions of a typical parking space (15,000 mm x 3,000 mm). Consequently, only the analysis of the parking locations that have sufficient parking space, apart from the designated sites, will be possible. The aspect of dimensions are crucial for the results obtained by Algorithm 2. All parameters related to Scenario 2 are presented in Table 3.

For this type of transport, it was determined that the time of implementation would be during the night (22:00 - 6:00), which in theory translates into a more efficient trip due to minimal traffic but on the other hand exposes the carrier to the

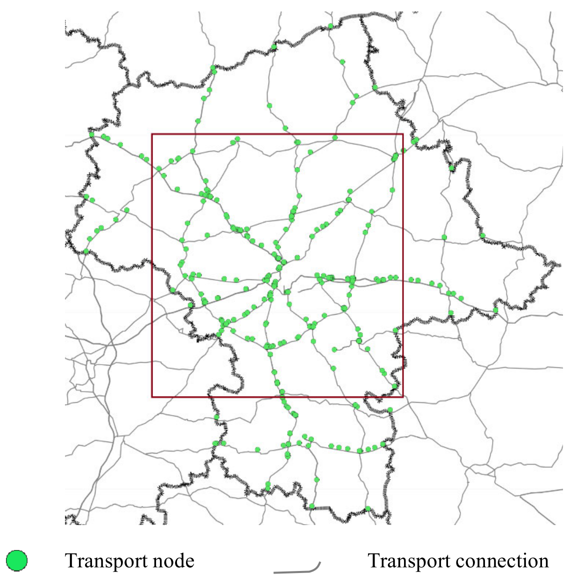

FIGURE 6. Analysed road network - the network of national roads in Mazovia Province.

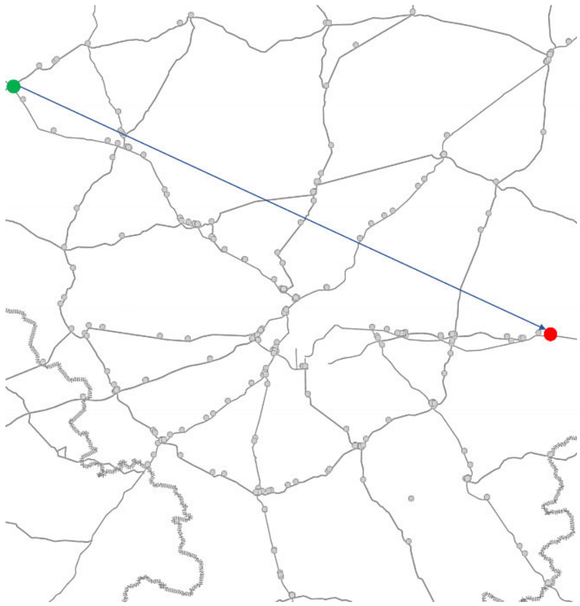

FIGURE 8. The direction of travel for 3 scenarios between cargo shipping and receiving nodes.

TABLE 2. Simulations configuration for vehicle with hazardous cargo.

Parameters	Values
Vehicle width (c_{wth})	3000 mm
Vehicle length (c_{len})	8000 mm
Hazardous cargo (c_{haz})	Yes
Valuable cargo (c_{val})	No
Maximum travel time (t_{max})	500 min
Starting time (t_0)	8:00
Single driving time restriction (t_s)	120 min
Daily driving time restriction (t_d)	240 min
Weekly driving time restriction (t_w)	400 min
Rest after single driving (s_{d_i})	15 min
Rest after daily driving (s_{n_i})	60 min
Rest after weekly driving (s_{w_i})	300 min

risk of not being able to find a place for a break in their trip s_{d_i} due to the implementation of daily rests by other drivers in individual parking places. However, for the purpose of the study, it was assumed that if at the time t at a given node $v \in P$ there is a parking space that can be occupied by an abnormal vehicle, it is not occupied by another vehicle of this type at that time. In addition, it was also specified that the actual capacity of the proposed vehicle to move in the analysed network will be ignored, which means that the vehicle can move along any transport connection. This fact is important because otherwise, it would be necessary to apply additional heuristics which are not the object of analysis.

TABLE 3. Simulations configuration for abnormal vehicle.

Parameters	Values
Vehicle width (c_{wth})	5000 mm
Vehicle length (c_{len})	40000 mm
Hazardous cargo (c_{haz})	No
Valuable cargo (c_{val})	No
Maximum travel time (t_{max})	400 min
Starting time (t_0)	22:00
Single driving time restriction (t_s)	60 min
Daily driving time restriction (t_d)	120 min
Weekly driving time restriction (t_w)	400 min
Rest after single driving (s_{d_i})	10 min
Rest after daily driving (s_{n_i})	90 min
Rest after weekly driving (s_{w_i})	450 min

TABLE 4. Simulations configuration for vehicle with valuable cargo.

Parameters	Values
Vehicle width (c_{wth})	2800 mm
Vehicle length (c_{len})	15000 mm
Hazardous cargo (c_{haz})	No
Valuable cargo (c_{val})	Yes
Maximum travel time (t_{max})	300 min
Starting time (t_0)	14:00
Single driving time restriction (t_s)	70 min
Daily driving time restriction (t_d)	130 min
Weekly driving time restriction (t_w)	400 min
Rest after single driving (s_{d_i})	4 min
Rest after daily driving (s_{n_i})	50 min
Rest after weekly driving (s_{w_i})	250 min

C. SCENARIO 3: A VEHICLE WITH VALUABLE CARGO

The specificity of a vehicle transporting valuable cargo requires an analysis of the availability of stopping locations, based primarily on security aspects. For the purposes of this study, it was assumed that the dimensions of the vehicle in Scenario 3 will allow parking in specially designated places, the number of which is specified for each parking lot. The individual travel times t_s, t_d, t_w defined for specific categories are similar to the values found in Scenario 2 although in this case Algorithm 2 will evaluate the parking place based on other considerations. All the parameters for Scenario 3 are highlighted in Table 4.

On account of the fact that valuable cargo generates the problem of determining appropriate parking locations, Algorithm 1 will perform calculations based on the locations characterised by a sufficient level of security $s(v)$, but for the analysis of the results mainly the criterion functions related to the occupancy and number of individual parking spaces will be used (6 - 7).

V. RESULTS AND DISCUSSION

Considering that calculations for the same transportation network are performed for all scenarios, it was determined that the potential number of routes in the proposed service between the shipping and receiving points equals 16. The routes for each scenario were analysed in terms of the parameters which allowed the assessment of the advisability of selecting individual solutions. These parameters were the total travel time t_t, the parameter of the security of the parking locations on the route μ, the parameter of parking location occupancy on the route ρ, the parameter of the average number of parking spaces per single parking location on the route τ and the parameter of traffic volume on the route $c\partial$, being the weighted average traffic volume on all transport connections making up the route. The parameter $c\partial$ took into account the actual data on the average travel time of vehicles returned by the Google Maps API compared to the travel time taking into account road traffic regulations without the occurrence of the phenomenon of congestion. For the purposes of the study, it was assumed that such assumptions will significantly reflect the actual state of road traffic for particular values t on subsequent transport connections.

The analysis of the solutions returned by the algorithm was also possible based on data on parking places. These data included aspects such as the type of stop, level of security $s(v)$, level of parking space occupancy p_{occ_i} for the time t in which the vehicle reached the transport node $\in vP$, as well as the number of total parking spaces reflecting the size of the parking location.

A. SCENARIO 1: A VEHICLE WITH HAZARDOUS CARGO

In the case of Scenario 1, which includes the trip of a vehicle with dangerous cargo, a simulation was performed which returned two possible routes for the input parameters given in Table 2. The characteristics of the obtained results are presented in Table 5.

Each of the obtained routes was characterised by one parking location of type s_{d_1}. The first route, consisting of 40 nodes, with a total travel time of 193 minutes, was characterized by parking space occupancy $\rho = 0.63$ for 1 parking space per a vehicle with dangerous cargo at a single parking location on the route, on average. The time duration t_t was influenced by the traffic volume coefficient ∂, which amounts to 1.08 for this variant. The parking determined by the algorithm for this route was characterised by the security level $s(v) = 0.5$ and for the range $p_{occ_{10}}$, in which it was necessary to stop at the indicated parking, the occupancy was 0.49. The second variant for Scenario 2 (a 50-node one) was characterised by a longer journey time of 236 minutes and slightly higher parameters ρ and ∂, amounting to 0.67 and 1.09, respectively. More significant differences are related to the characteristics of the parking, which in this case was occupied at the level of 0.83, which is a value only 0.02 lower than the permissible limit value. Taking into account the fact that the security parameters of the parkings along the route μ, as well as ρ, τ and ∂ are similar, and the parkings differ significantly in the level of occupancy at the same level of security and the number of available places for vehicles with dangerous cargo, the route consisting of 40 nodes could be much more attractive for a carrier. The aspect of total travel time also supports it, which, in this case, is also more favourable. The simulation time in both cases was comparable - 44 ms and 56 ms. The time needed to return each route based on the query *theshortestpath*() using Neo4j, for later analysis using Algorithm 2, was 37 ms and 46 ms, respectively.

B. SCENARIO 2: AN ABNORMAL VEHICLE

In Scenario 2, based on the trip of an abnormal vehicle for the input data from Table 3, it was possible to obtain three solutions based on the proposed algorithms. These solutions are listed in Table 6.

The first of the obtained routes, consisting of 36 nodes, was characterized by a relatively low occupancy coefficient $\rho = 0.33$ with an average of 18 parking spaces per one parking. These values clearly stand out from the other routes, for which the aforementioned parameters were respectively $\rho = 0.64$ and $\tau = 16$ for the 40-node route and $\rho = 0.44$ and $\tau = 17$ for the 48-node route. On the other hand, the travel time along this route is over 10% longer than along the other routes. This also translates into an increased number of stops, which for a route consisting of 36 nodes was estimated at 4 - 3 individual driving breaks and one daily rest. In the case of an abnormal vehicle, each stop may generate the need to stop the traffic from the opposite direction and involve problematic vehicle manoeuvring (sharp turn). The 40-node and 48-node routes contain 3 stops each - 2 single driving breaks and one daily rest, but for the former, the load values for the designated parkings are significant, and the stop of the type s_{n_i} is planned in a location with occupancy close to its limit. Although this occupancy does not apply directly to the abnormal vehicle, it affects the available space and the difficulty in manoeuvring. The attractiveness of the 48-node route compared to the 40-node route is supported by both the travel time and the attractive value of the parameter ρ, as well as a daily rest at a location with occupancy equal to $p_{occ_2} = 0.13$. In Scenario 2, the values of the route security parameter μ are not so significant, although, in this category, the 40-node route stands out with a value above 0.5. The 36-node route, despite the relatively attractive security level $s(v)$ of the designated parking, is characterised by a value of this parameter at the level of 0.48. The simulation time for the presented routes did not differ significantly (from 60 ms to 84 ms). However, the increase in this value was mainly due to the need to plan several stops along the analysed routes and the size of the set of analysed nodes along the route.

C. SCENARIO 3: THE VEHICLE WITH VALUEABLE CARGO

Scenario 3 was based on the movement of a vehicle with valuable cargo for which the primary criterion for selecting a stop was the security of the parking on the route. The conducted research indicated six possible routes for the data contained in Table 4, and the obtained results are highlighted in Table 7.

When analysing the table above, it can be noted that the 34-node and 39-node route have similar characteristics.

TABLE 5. Simulations results for the vehicle with hazardous cargo.

Nodes in route	Route parameters					Parking parameters				Simulation time (ms)
	t_t (min)	μ	ρ	τ	∂	Type of stop	$s(v)$	p_{occ_i}	p_{haz}	
40	193	0.54	0.63	1	1.08	s_{d_1}	0.5	0.49	3	44
50	236	0.5	0.67	1	1.09	s_{d_1}	0.5	0.83	3	56

TABLE 6. Simulations results for the abnormal vehicle.

Nodes in route	Route parameters					Parking parameters				Simulation time (ms)
	t_t (min)	μ	ρ	τ	∂	Type of stop	$s(v)$	p_{occ_i}	p_{slo}	
36	326	0.48	0.33	18	1.01	s_{d_1}	0.25	0.6	30	60
						s_{d_2}	0.5	0.2	17	
						s_{n_1}	0.75	0.1	50	
						s_{d_3}	0.75	0.73	27	
40	288	0.54	0.64	16	1.02	s_{d_1}	0.25	0.6	30	69
						s_{n_1}	0.5	0.81	54	
						s_{d_2}	0.75	0.73	27	
48	288	0.5	0.44	17	1	s_{d_1}	0.25	0.6	30	84
						s_{d_2}	0.75	0.48	26	
						s_{n_1}	0.25	0.13	34	

The similarity is also visible for routes consisting of 36 nodes and 41 nodes.

The similarities result from the accuracy of mapping the transport network, where many possibilities of travelling through relatively short transport connections (e.g., at road junctions) occur. The 34-node and 39-node routes are characterised by the value of the parameter μ at the level of 0.5, and the average occupancy level ρ in the analysed time intervals at the level of 0.48. The algorithm assigned the same parkings in both cases - two of them in the case of having a driving break and one for a daily rest. The places where the stops s_{d_2} and s_{n_1} take place are characterised by significant occupancy in the analysed hourly intervals, amounting to over 0.7. Moreover, in the case of the stop s_{d_2}, it is carried out at the parking, where the number of slots allocated for trucks is only 5. This fact significantly influences the assessment of the route, for which the probability of not being able to stop at the designated place is high. In the case of the 36-node and 41-node routes, the algorithm determined that the security level μ is slightly lower (0.48) than for the 34-node and 39-node routes, although with the simultaneous reduction in the occupancy level to 0.38 and increasing the number of parking spaces per single parking from 15 to 19. Unfortunately, these variants contain identical parkings as in the previous case, with such difference that there is an additional driving break, and the associated parking has a low occupancy level $p_{occ_{19}} = 0.1$ with a considerably large number of parking spaces. Additionally, the travel time t_t is longer for these routes by over 30 minutes. Another variant which stands out from the results discussed is a route consisting of 46 nodes. The parameter μ is as high as 0.56 for it, with a relatively low occupancy ρ at the level of 0.42. Moreover, there are 17 parking spaces for a single parking on this route, which is a better result than the result obtained for the 34-node and 39 - node routes (15 slots). The attractiveness of this route is also influenced by the fact that it features 3 stops - two driving breaks and one daily rest, for which the occupancy in the analysed time intervals is acceptable. Admittedly, one of the parkings has only 7 parking spaces, but the occupancy of 0.01 practically guarantees that one can have a rest at this node. On the other hand, the travel time t_t of 256 minutes is more favorable than the travel time obtained for the 36-node and 41-node routes. The last analysed result returned by the algorithm is a route composed of 48 nodes. The characteristics of this route indicate that it is a compromise between the previously analysed routes. This conclusion is influenced by the fact that the travel time t_t in this case is 236 minutes, with a satisfactory overall security level of the parkings along the route (0.5), with an acceptable occupancy level of 0.5. Furthermore, the number of parking spaces per single parking was as high as 22 slots. For the above-mentioned route, the algorithm determined 3 stops and special attention should be paid to the size of parking lots (up to 90 slots), where the number of available parking spaces is significant with occupancy $p_{occ_{15}} - p_{occ_{18}}$. The time of individual simulations depending on the number of analysed nodes ranged from 52 ms to 82 ms.

Comparing the proposed solution to the approaches found in literature, it seems that it is one of the few attempts of combining aspects related to the planning of vehicle stops. This fact makes it difficult to directly compare the Algorithm with other methods. For example, Vital and Ioannou modelled a solution for trucks [22] and there is a similarity with the assumptions of the driver's working time (8-9 and 10-12) in both articles. However, the authors assumed that each

TABLE 7. Simulations results for the vehicle with valuable cargo.

Nodes in route	Route parameters					Parking parameters				Simulation time (ms)
	t_t (min)	μ	ρ	τ	∂	Type of stop	$s(v)$	p_{occ_i}	p_{slo}	
34	223	0.5	0.48	15	1.06	s_{d_1}	0.75	0.39	68	52
						s_{d_2}	0.75	0.74	5	
						s_{n_1}	0.75	0.73	27	
36	268	0.48	0.38	19	1.06	s_{d_1}	0.75	0.39	68	63
						s_{d_2}	0.75	0.74	5	
						s_{n_1}	0.75	0.1	50	
						s_{d_3}	0.75	0.73	27	
39	231	0.5	0.48	15	1.04	s_{d_1}	0.75	0.39	68	58
						s_{d_2}	0.75	0.74	5	
						s_{n_1}	0.75	0.73	27	
41	277	0.48	0.38	19	1.05	s_{d_1}	0.75	0.39	68	68
						s_{d_2}	0.75	0.74	5	
						s_{n_1}	0.75	0.1	50	
						s_{d_3}	0.75	0.73	27	
46	256	0.56	0.42	17	1.06	s_{d_1}	0.75	0.48	26	76
						s_{d_2}	0.75	0.01	7	
						s_{n_1}	0.75	0.73	27	
48	236	0.5	0.5	22	1.05	s_{d_1}	0.75	0.48	26	82
						s_{d_2}	0.75	0.39	54	
						s_{n_1}	0.75	0.71	90	

vehicle can stop in a parking lot whose occupancy is satisfactory. In fact, there are a number of vehicles for which such assumptions are insufficient. On the other hand, Vital and Ioannou approach makes direct comparisons of alternative routes, which is an undoubted advantage.

The experiments have shown that in the works describing the driver's working time from the point of view of VRP, it is very important to take into account the phenomenon of congestion. On some routes there were an almost 10% delays in relation to the free flow of traffic. Such a deviation causes that scheduling which does not include this phenomenon is limited and may cause distortions, which is also noted in the literature [22].

Yujin, who took into account the phenomenon of congestion and developed the balance function on its basis, limited himself only to the analysis of the car park occupancy, without considering its parameters and equipment [9]. It is worth noting that a vehicle entering a parking space without knowing the current rate of occupancy generates additional traffic. The authors of this paper follow an approach where the occupancy should be known or estimated before selecting a parking space.

Comparing the method with the Rosita approach [4], the authors decided to assign the risk to the point infrastructure instead of the road section. This is due to the type of cargo being transported and the greater predictability of risk. In the developed method, this risk results from the equipment of parking lots and translates into the probability of a collision in a parking space, more serious consequences of an incident involving dangerous goods, the likelihood of theft and the likelihood of breaking the driver's working time regulations. The authors believe that this approach should be considered by the authors of the work [4].

VI. CONCLUSION AND RECOMMENDATIONS

The problem of determining the route for vehicles requiring special parking conditions is an issue which requires identifying the needs related to the technical parameters of vehicles, taking into account the traffic regulations, and the characteristics of the cargo being transported. The presented research focused on defining the basic types of vehicles based on a mathematical model, categorizing parkings, and developing an algorithm on the basis of which the VRP problem can be solved for the adopted range of cases, using graph databases.

During the development of the mathematical model, the focus was placed on the largest groups of vehicles with the aforementioned characteristics. It should be borne in mind that there are also additional groups of vehicles whose needs may be based on aspects other than those distinguished in this study, for example access to electricity at the parking, with which to supply the vehicle's equipment. In addition, the solution developed was based on an approach in which the occupancy at the parking was recorded around the clock. In reality, these solutions are only in the implementation phase because of the development of image-based recognition based on artificial neural networks. This is a direction in the development of parking systems which will certainly be continued and will become the foundation for many other systems supporting the process of transport planning. The proposed model can also be extended to include aspects related to the technical parameters of parking, different approach to their design and parking space layout, and logical conditions allowing the assessment of vehicle manoeuvrability.

The results obtained demonstrate the effectiveness of the algorithm for mapping a real transport network. The adopted criteria allowed for assessing the validity of selecting a particular route, even taking into account aspects which were not directly related to the needs resulting from the nature of a given transport. In the case of hazardous cargo transport, it was possible to highlight a route which was both shorter and for which a high probability of finding a parking space in the analysed time interval was determined. The algorithm determined routes for an abnormal vehicle which allowed comparisons to be made based on the number of driving breaks, parking occupancy and the level of security. The variant consisting of a vehicle carrying valuable cargo was based on 6 returned results, which were analysed mainly with respect to the security level of the route, the number and occupancy level of parking and the number of slots provided for trucks. The results obtained are important insofar as they provide, in a sense, an opportunity to assess the capacity of the parking infrastructure in a given area, but also make it possible to choose a route based on the knowledge being a safeguard in the case of an unforeseen event. For example, if delays occur due to traffic obstructions and the necessity to stop, a route with a high value of the parameters μ and ρ, would give the possibility of an emergency stop at any node $v \in P$ with a high probability of finding a free space and a satisfactory level of security.

Analysing the solutions obtained in the course of algorithm iteration, one notices the necessity of extending it with mechanisms simulating different variants of stops for each of the analysed routes. It is possible that the result of the procedure of returning from the node where the values stemming from traffic regulations have been exceeded to the first node with a stop meeting the specified conditions will not be the best possible one. In such a case, retreating along the subsequent route nodes may result in finding a more attractive parking with a relatively small time loss resulting from the desire to maximize the time of a single trip.

The application nature of the solution and its compatibility with the API of services supporting road transport allow it to be scaled for larger networks or implemented in existing systems. The algorithm can be extended with additional mechanisms based on AI [50], [66] to obtain even more accurate forecasts, and create simulations for many driving scenarios.

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IGOR BETKIER received the M.Eng. degree in logistics with movement and transportation specialization from the Military University of Technology, Warsaw, Poland, in 2017, and the Ph.D. degree in civil engineering and transportation from the Warsaw University of Technology, Poland, in 2021. He is currently a Research Assistant with the Institute of Logistics, Military University of Technology. His research interests include the transportation software development, vehicle routing problem (VRP), transportation planning, transport safety, and AI application in transportation problems.

JOLANTA KATARZYNA ZAK received the M.Sc. degree in mathematics from the University of Warsaw, Poland, in 1998, and the Ph.D. degree in civil engineering and transportation from the Warsaw University of Technology, Warsaw, Poland, in 2005. Since 2017, she has been an Associate Professor with the Faculty of Transport, Warsaw University of Technology. She is the author of four books and more than 80 articles. Her research interests include mathematical modeling, transport processes, multicriteria analysis, and fuzzy sets.

SZYMON MITKOW received the M.Eng. degree in electromechanics from the Military University of Technology, Warsaw, Poland, in 1995, and the Ph.D. degree in machine design and maintenance from the Air Force Institute of Technology, Warsaw, in 2004. He has been the Dean of the Faculty of Security, Logistics and Management, Military University of Technology, since 2017, where he has been an Associate Professor, since 2016. His research and teaching activities include national defense security, forecasting of the defense security environment, assessment of defense capabilities, acquisition of military equipment, military and business logistics, transport, use of quantitative and qualitative methods in security and logistics, and development and evaluation of military technology.

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