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THE USE OF THE ROADLOAD APPLICATION IN GEOGRAPHICAL STUDIES OF FLOWS GENERATED BY INDIVIDUAL MODES OF TRANSPORT

Summary. The purpose of this article is to present the authors' own software for predicting changes in the density and directions of traffic flows and to compare overall results of research on transport accessibility with the results returned in the study of transport accessibility conducted with the software (isochronic accessibility). Developed for research purposes, the authors' application is based on Dijkstra's algorithm, which is classified as one of the greedy ones and does not always return optimum results, even though it is considered to be generally accurate. In the course of the research, it was stated that the implementation of Dijkstra's algorithm in the RoadLoad tool is suitable for studying and prognosing phenomena, under the assumption that there are detailed data on the point of departure and destination for each trip. The tool enables us to research a spatial (cumulated values of network load) as well as time-spatial (network load at virtually any time) dimension of the phenomenon. It cannot be applied, however, without the knowledge of the transport behavior characteristics of the users of the road system.

1. INTRODUCTION

When described by geographers, space is characterized by three fundamental attributes, i.e., differentiation, resistance, and boundaries, where the first two crucially shape the demand for transport in response to a spatial discrepancy between the elements necessary for the functioning of the socio-economic system. Therefore, spatial differentiation creates conditions for the development of transport, whereas spatial resistance – which is not identical for different places and at a different time – influences the manner in which space is covered, namely, how the mode of transport and the route are selected. In this context, the third attribute of space, i.e., its boundaries, can take various forms, as they may constitute persistent barriers in transport, or they might be designated arbitrarily and exclusively for the purposes of the research procedure. The aforementioned arbitrariness stems from the research needs to present transport phenomena in individual territorial units, or it may also be one of the methodological assumptions which allow for the presentation of spatial phenomena in narrower aspects of space (it happens to be established on the basis of various types of delimitations and adopted on the basis of administrative divisions of space).

This introductory paragraph constitutes, to a certain extent, a base for further deliberations on movement, called 'mobility' in the subject literature, where the concept of mobility is by no means unambiguous, as 'many academic theorizations of movement have tended to view mobility as something other than the norm' [1, p. 77). On the contrary, on the basis of the philosophy by

Heraclitus of Ephesus, concisely put in the famous statement of panta rhei, and the modern approaches by Bergson [7] and their subsequent re-evaluations [17], mobility is currently perceived as a normal state. Thus, if everything is in motion, for cognitive purposes, it is worth trying to discover the mechanisms that govern it, even more so because the right to mobility is one of the fundamental rights of free society, and as each human activity is related to mobility, its restriction is an act detrimental to our quality of life [51].

When attempting to synthesize the afore-presented theoretical background for the purposes of geographical studies, and more precisely, for the needs of transport geography, it is worth considering several opinions on 'mobility' that are commonly encountered in the literature. Some understand mobility as the movement of people, objects, capital, and information on various spatial scales [16, 23], whereas others indicate that mobility is a potential (an ability) to cover space [3, 55]. Kaufmann, Bergman, and Joye [29] believe that spatial mobility traditionally refers to geographic displacement, i.e. the movement of entities from an origin to a destination along a specific trajectory that can be described in terms of space and time. Entities can be concrete (e.g. consumables, machinery, or people) or abstract (e.g. information, ideas, or norms). During this journey, entities may not only experience a change in status (e.g. value or importance), but the spatial mobility of entities may also influence the points of departure, traversal, or destination (p. 746). Another noteworthy issue is that studies in spatial mobility are aimed at analyzing the processes of territorial motility in specific geographical conditions [32, 39]. Thus, research on spatial mobility includes studies of migration, tourism, as well as residential and daily mobility in urban areas [27]. This article also focuses on methods of researching daily mobility, understood as the entirety of residents' every day, recurrent trips connected, for instance, to commuting to the workplace.

The process of mobility affects other journeys in real time. This stems from the fact that it is conducted within transport systems, which are sets of elements linked to one another and their surroundings [8]. Accordingly, the supply to meet the demand for mobility is guaranteed by a spatially determined set of elements used to travel, and their mutual connections and relationships with other areas of socio-economic life. At the same time, it must be noted that mutual interrelations between the elements of the system and their reciprocal influences are extremely powerful and can be scrutinized from various perspectives, including inter-sub-systematic and intra-sub-systematic views. The former can be illustrated with the example of the relation between modes of the subsystem of public transport and the use of private cars [6, 20, 36, 37, 41, 47], whereas the latter is exemplified by research into the effect of traffic density on choices made by car users [28, 43, 46], which - besides its scientific and planning applications - is also reflected in the everyday life of, for instance, the high demand car users have for navigation solutions with real-time traffic functionality, eagerly addressed by global players in the industry. In view of the aforementioned, this article focuses on presenting methods of researching daily mobility from the perspective of the subsystem of individual car transport.

Similarly, it should be noted that one of the effects of daily mobility is traffic density within the road network, which is conditioned by drivers' habits and preferences for various modes of transport, and on the rate of car ownership. Owing to its technical parameters, the aforementioned network is characterized by capacity limitations in all of its individual segments, which lead to disruptions that may be divided into atypical and typical [14]. The former are the result of specific and momentary conditions and circumstances and lead to the occurrence of random congestion (non-recurring congestion) [15, 44, 59]. What is also worth noticing here is that the vast majority of atypical disruptions result in negative consequences for road traffic (although the degree to which the network is disrupted may vary, depending on the type and spatial range of the cause), and yet, not all of them are characterized by the same level of randomness or are as equally difficult to predict. Typical disruptions are usually of a cyclical nature and are generated by inequalities of transport demand in time and space (recurring or recurrent congestion).

Finally, the issues related to daily mobility are inextricably linked to the concept of accessibility, which is defined differently in the subject literature. References to this term can be found, for instance, in publications by Gould [21], Hansen [24], Ingram [25], Vickerman [54], Handy and Niemeier [22], Bruinsma, Rietveld [12], Martellato, Nijkamp and Reggiani [38], Taylor [53], and Wiśniewski [57]. Synthetically speaking, it seems to be legitimate to state that accessibility is the potential for interactions to occur, where the potential can be conditioned by numerous and miscellaneous factors. In a scenario where one of these factors is the transport system, we are talking about transport accessibility. From this perspective, the more points there are that can be accessed quickly, cheaply, and efficiently, the more accessible any given point within the area will be. Black and Conroy [9] define transport accessibility as the ease with which a venue of a given activity can be reached in space from a certain location and by means of a specified mode of transport. Cauvin [13] describes it as a measurable value of the spatial distance between a given location and points to which it would like to be linked by a selected mode of transport. There are numerous approaches to the study of transport accessibility [12]. Rosik [42] presents a synthetic division of five methods to research and measure transport accessibility, one of which is the approach called cumulative accessibility, containing the method referred to as isochronic accessibility. It involves evaluating a set of destinations, or a set of potential departure points of trips to a given analyzed location, which are accessible upon the allocation of a given amount of time. The research is conducted on the basis of a specified mode of transport. As the application of this method does not include a direct assumption of the Euclidean distance, the evaluation of travel speed, and thus, also travel time pose a problem. Therefore, this type of research requires numerous simplifications such as, above all, the human inclination to minimize as far as possible the travel time between the point of departure and destination [45]. The application of the strategy of homo economicus in such studies – where rationalization is expressed as a maximization of the time required to complete a given objective – may be assessed critically. On the contrary, however, transport behavior is affected by so many factors that taking them all into account seems virtually impossible. These factors include drivers' attitudes (disposition) and tendency to exceed speed limits, the quality of modes of transport (age, technical condition, performance and acceleration, and maximum speed), the system of penalties for breaking traffic regulations, etc. Therefore, modelling of car traffic flow in order to accurately simulate real traffic conditions is one of the most demanding challenges of transport geography and road traffic engineering. As a result, various methods to evaluate travel time are implemented in geography, from studies in which the assumed travel time is calculated based on the traffic regulations within the Traffic Law Act [58], through a direct (and thus, somewhat subjective) measurement conducted by the researcher themselves, who travels along a given road network [4], to more advanced models which take into consideration, for instance, official speed limits, natural topography around the road network, numbers of residents living in the vicinity of a given road [30], traffic density [2], as well as models based on real-time traffic data [57]. All the aforementioned solutions do not take into account changes in traffic density measured in real time or close to real time (quasi real-time measurement) (The concept of 'real time' contains linearity of some sort. Here, the quasi-real time should be understood as a set of images taken at a determinable frequency). Naturally, taking such changes into consideration does not, by itself, guarantee that drivers are fully aware of congestion within the network, always act rationally, and thus, are able to recalculate travel times for alternative routes. It seems, however, to be worth checking and comparing the results returned when the factor is taken into account with the results obtained by methods more common in the subject literature.

The aforementioned inescapable link stems from the presence of feedbacks occurring between mobility and accessibility, which are based on two key vectors. The conditions improving transport accessibility facilitate mobility (higher supply generates lower costs related to overcoming the resistance of space, which – in turn – increases the demand for transportation). On the contrary, higher demand for transportation hampers traffic within the network (the aforementioned typical disruptions), which negatively affects transport accessibility (especially time and money).

In respect of the aforementioned theoretical deliberations, the main purpose of the study is formulated, as the article is intended to present the authors' own software for predicting changes in the density and directions of traffic flows, and to compare other results of research on transport accessibility with the results returned in the study on transport accessibility conducted with this tool (isochronic accessibility). Additionally, initial specifications entered into the application are assessed and solutions to break the methodological impasse are indicated.

2. AN INTRODUCTION TO THE METHODOLOGY

The authors' application, developed for research purposes, is based on Dijkstra's algorithm [18], aimed at designating the shortest distance between a specified node *s* and all remaining nodes within the directed graph, when it is assumed that there are no negative-weight edges in the indegree. The algorithm remembers the set *Q* of nodes for which the shortest paths have not been calculated and the vector D_i of the distance between the node *s* and *i*. Initially, the set *Q* contains all the nodes, and the vector *D* is the first line of the matrix of the weights within edge *A*. While the set *Q* remains empty, the algorithm orders (1) the node *v* with the smallest value $D_{[v]}$ to be derived and deleted from the set *Q*, and (2) the relaxation of the path for each successor *i* of the node *v*. Owing to its algorithmic paradigm, this algorithm is greedy, and thus, it does not always return an optimal result, even if it is considered to be an accurate solution. As indicated, for instance, by Jasika et al. [26], Dijkstra's algorithm in itself is sequential, and difficult to parallelize, as average speed-up ratio achieved by parallelization is only 10%. This proves to be a huge disadvantage of this algorithm, because its use is widespread, and enhancing its performance would have great effects in its many uses, including improvements in this range.

First, let us focus on the operating principles of the application itself. As far as data are concerned, it relies on .csv files that contain information on nodes and edges of the road network to be analyzed. Nodes represent points of departure, destinations, and all road intersections, whereas edges – sections of roads between the nodes. Each edge is attributed with specified parameters (their number is limited and is dependent on the purpose of the study), which determine the weight of a given section within the network. Each edge is also obligatorily attributed with an ID number, the maximum capacity (number of vehicles/time unit), as well as the ID number of the departure and destination node. It is also imperative to enter at least one variable (e.g., travel time for a given section), on the basis of which an optimum route will be designated. Subsequent introduction of successive variables (e.g., technical condition of the road, number of lanes within the carriageway, or the travel cost) is optional and depends exclusively on the purpose of the study. The researcher decides how many variables will be taken into consideration during the process of calculating an optimum travel path, and thus, it may only be a single feature or a combination of numerous factors (e.g., the fastest, the cheapest, and the most convenient route). Nodes, however, are attributed with an ID number, the number of vehicles that depart from a given node, and an ID number that identifies the node or nodes which the vehicles are expected to reach. An extremely valuable feature is the possibility to describe the nodes from which vehicles set off with an initial delay time for 'transport packages'. Therefore, the researcher may decide on the departure chronology for vehicles in individual nodes. In order to calculate the level of load for individual elements of the network, the software groups vehicles into abstract objects called transport packages. Before starting the algorithm, the user may determine the maximum capacity (number of vehicles) for these packages (Thus, the tool is also an instrument for research on a micro- and mesoscopic scale). The operations of the tool are based on a mechanism of turns, where each turn lasts for a precisely stipulated length of time, during which the transport packages are moved along the network. The length of the turn also depends on the researcher and is established before calculations commence. Upon the implementation of the aforesaid settings, ancillary objects are generated, the most important of which are: the weight strategy and the path calculator.

On the basis of the entered .csv files and the aforementioned configuration, the application creates transport packages, and, at the same time, it determines their location on source nodes and calculates the most effective (depending on the initial settings, it might be the fastest, the shortest, the cheapest, etc.) route to the destination node, only taking into account the characteristics of the network, without considering its actual density (time, distance, economic and theoretical effectiveness, etc.). Subsequent introduction of successive variables (besides travel time) into the process of designating an optimum travel path translates into tangible changes in the load of various sections of the road network (Fig. 1).

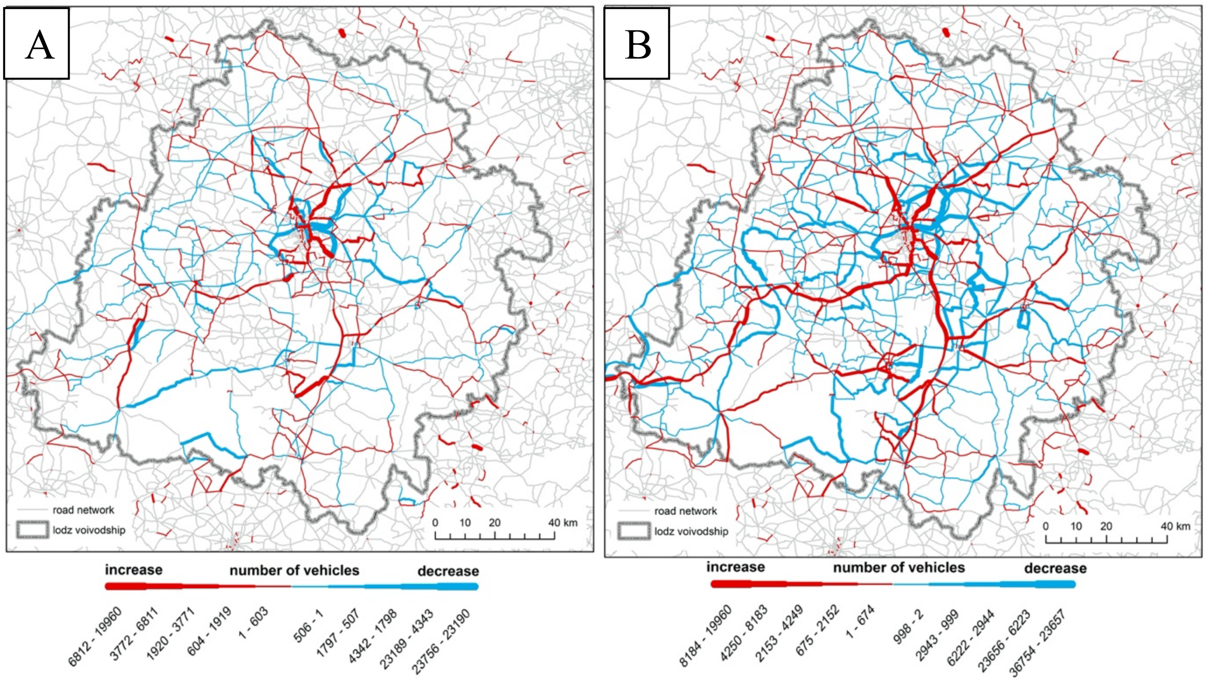

Fig. 1. Changes in the load of the road network within the Łódź region (central Poland), stemming from the introduction of the following variables into the analysis: A – number of lanes within the carriageway, B – technical condition, when compared with the analysis that exclusively takes into account travel time. The trips shown are commuter traffic within the Łódź region

The main loop of the application is built around an algorithmized selection of those transport packages that have not yet reached their destination or have exceeded the time of their delayed departure (for each departure node, departure time is determined so that vehicles could make it to their destination on time, within the assumed theoretical travel time). When synthesizing, the application chooses those transport packages that are on the road (it ignores the packages that are waiting to depart or have already reached their destination). Another step is to increase the iteration of the internal turn counter of the application. The counter was implemented in the algorithm to determine at what instant of a given turn any given transport package should join the traffic. Then, the algorithm moves all transport packages (in accordance with the aforementioned settings). The transport packages that have reached their destinations within a given turn do not take part in further calculations and are transferred to a dedicated results list. After each turn, the software generates a report file, containing information on the load of the network edges and the level of congestion within the nodes (Fig. 2).

The aforementioned stage at which the algorithm moves the transport packages is divided into two phases. During the first, an attempt is made to move all transport packages along their routes in accordance with the following plan: move a package along the edge of the graph where it is currently located (a node or an edge) by the amount of available time ⇒ if, once having been moved, a transport package has no more time available to move, set its status to 'moved' ⇒ if, once having been moved, a transport package does not have the 'moved' status, check the next point on its route, and if the point is blocked (i.e., there are too many vehicles there) or if it does not exist (The application contains an adaptation of Dijkstra's algorithm which assumes that – if it is not possible to mark out the route from point A to B, since such a route does not exist (or because all roads are blocked) – the system determines the route as non-existent. Thus, it is the only case when a transport pckage may not have a next point on its route (it is stuck in traffic)), a transport package is added to the list of blocked packages (stuck in traffic), and if the next point is not blocked – the transport package is moved there and the movement operation is repeated within the amount of time that the transport package still has in a given turn ⇒ once the time allocated for each transport package is depleted, select the packages with the 'blocked' status (Fig. 3).

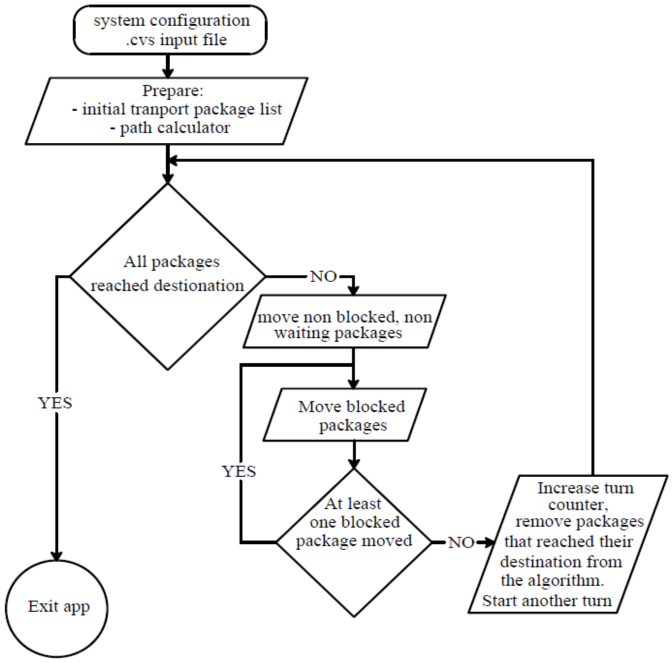

Fig. 2. Aplication flow (simplified)

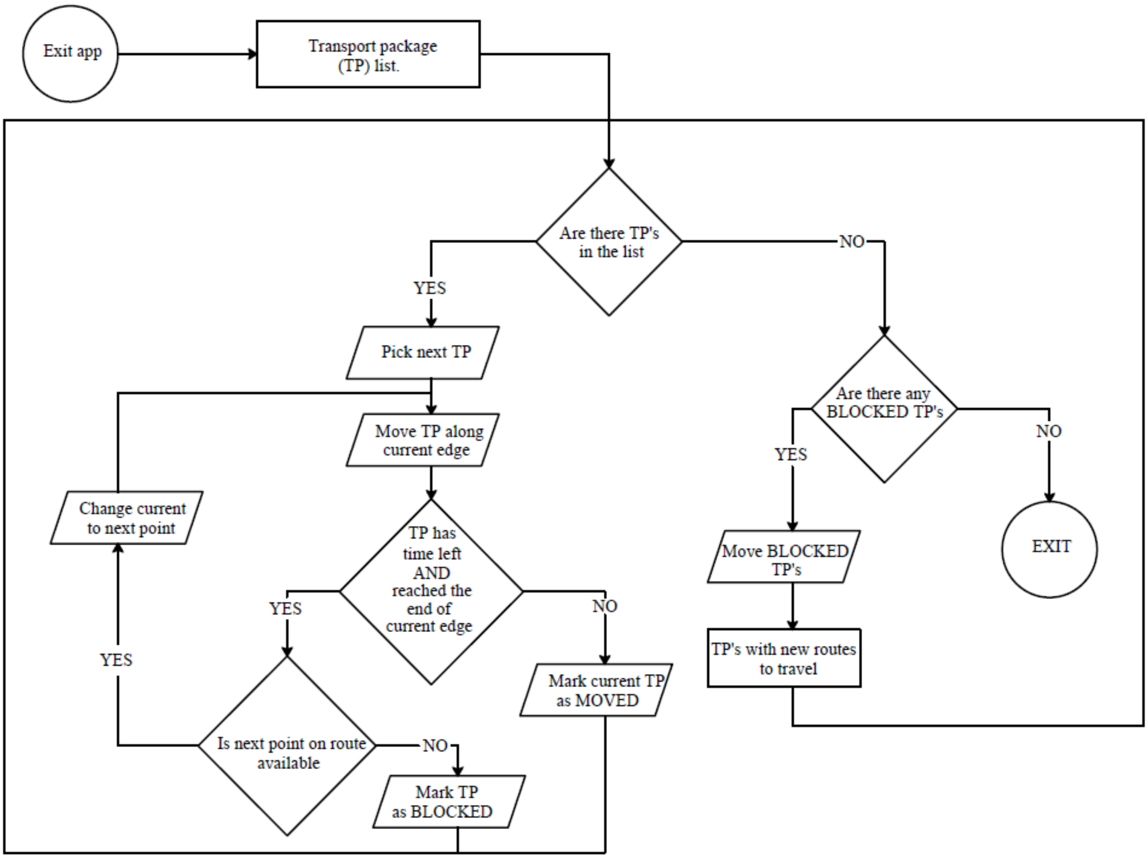

Fig. 3. Moving a transport package (TP)

The second phase, implemented whenever the list of blocked packages is not empty, is introduced in accordance with the following scheme: count the number of transport packages blocked during the first stage ⇒ generate a second list of blocked packages which will contain blocked packages isolated during the second phase ⇒ for each of the blocked packages, derive its position at a given time ⇒ move the package along the edge on which it can be found ⇒ if the package still has some time available, check the next point on its current route ⇒ if the point does not exist or is blocked, add the package to the second list of blocked packages ⇒ if the next point does exist and is not blocked, move the package to that point and repeat the procedures within the second phase. Once all attempts to move transport packages have been made, the algorithm compares the number of items on the two lists of blocked packages (compiled during the first and second phase). If the first list is longer, it means that one of the transport packages has moved and may have unblocked the possibility of movement for the other blocked packages (Fig. 4).

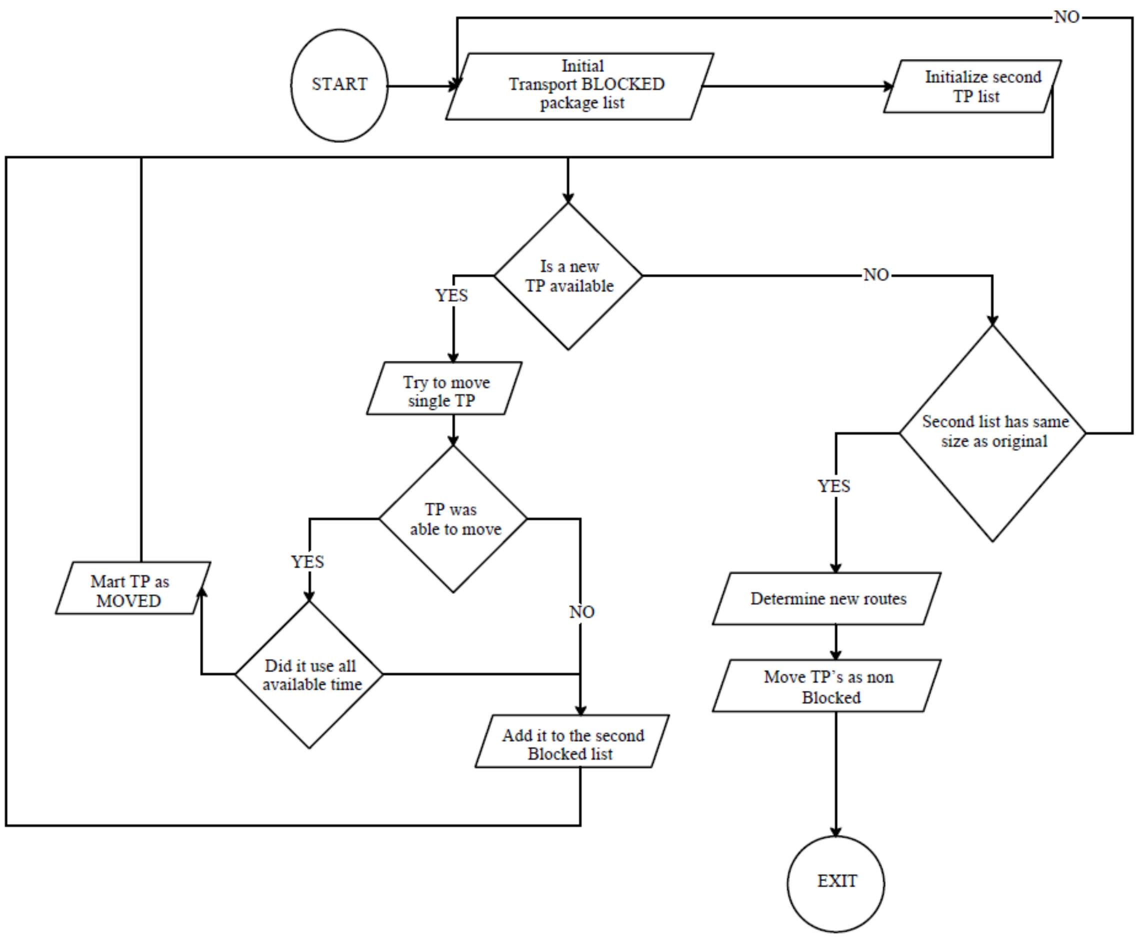

Fig. 4. Moving a blocked transport package (TP)

In such circumstances, the algorithm reinitiates the second phase. This time, however, the first list of blocked packages contains the number of packages from the latter list that was generated in the previous run of the process. The process terminates when both lists are equal, i.e., blocked packages have no possibility to move. Then, the algorithm designates a new route to the destination for those packages. Once a new route is marked out, the application recurrently initiates the function of package movement exclusively for those transport packages (the first and possibly the second phase being necessary).

Against a background of the methodological introduction, the research conducted by means of the authors' software is presented in the following sections of the article, including the discussion on the entry data applied in transport geography, as well as some methodological impasses and the solutions employed to break them.

3. USING THE APPLICATION TO RESEARCH REGION-TO-REGION MOBILITY

At present, the available statistics on mobility leave a lot to be desired in many countries, including Poland. As a result of this paucity, scientists have no spatial data related to trips, and more precisely, to their departure points and destinations. In Poland, these data are aggregate to the level of the municipality, which poses some analytical problems.

The application of the tool for studies on interregional mobility, i.e., focusing on trips aggregated, inter alia, to administrative borders (of a municipality, region, etc.), provides the researcher with a formidable challenge of determining both the departure point and destination. The authors' tool was used to conduct analysis in studies on daily mobility related to commuter traffic in the region of Łódź, Poland [11]. It was assumed that the beginning and the end of a trip is located within the node of the road network that is located in the closest Euclidean distance from the geometrical centroid of the unit from, or to, which trips are made. The assumption of the centroid as such is commonly applied in network research at this territorial level, and the centroid itself is designated by means of various approaches [5, 33, 35, 48, 49, 50, 52, 56]. Nevertheless, in the presented method, this process is by no means ideal, which stems from two fundamental factors. First, and perhaps slightly less importantly, beginning a journey from a single point results in a substantial load of the edge (road) stretching from the departure point to subsequent nodes within the route. Even more difficulties – upon the application of a method of designating departure points and destinations – result from reducing their sets to a single point, as the model may be much less realistic than desired. In studies that involve analyses of the achievement of destinations by a certain time, it leads to an extreme loading of edges adjacent to the destination node, and in the case of extensive mobility, it also results in a methodological 'super-congestion' in the whole area around the destination point. In consequence, it provides an unclear picture of vehicle travel time, which – to an unacceptable extent – differs from the theoretical travel time (determined on the basis of the maximum allowable speed) and is virtually never observed in reality.

Therefore, several solutions were introduced to eliminate this error. First, instead of assuming the centroid to be the departure and destination point, one can apply a number of points within the territorial unit that are positioned geometrically and evenly from one another, whose exact number should be determined on the basis of the size of the territorial unit. This would create a picture of the unit as an object with perfectly dispersed deployment of homes and workplaces. In this case, however, what may pose a problem is the selection of the departure point for individual transport packages. To deal with this, it could be assumed that vehicles departing in a given direction (heading for the same region) should be divided equally (with the assumption that the quotient must be an integer). A similar assumption may apply to vehicles travelling to a given municipality.

Another approach to break the methodological impasse is to create 'artificial' departure and destination nodes at the intersections of borders of administrative units, and to simulate the traffic which would start and/or finish within them. A modification to this approach is the application of a specified buffer from the centroid of the administrative unit to create 'artificial' nodes, as it illustrates the management of units in a slightly better manner. This method can be applied when a strong concentration of departure points and destinations is observed within the central area – the specific 'city center' of the territorial unit.

The third solution entails the implementation of the principle that roads around the centroid where traffic is directed (or which is a destination) have an unlimited capacity, thus assuming that congestion is impossible on the roads directly adjacent to the node designating a final destination. One must, however, point to another limitation here, as the aforementioned road sections can form one of the transit routes, and therefore, this assumption may, to a certain extent, show an acceleration of travel times.

As the application of all the aforementioned models requires some methodological limitations and simplifications, the final choice of solution should be based on a previously conducted analysis of the transport network so as to eliminate the largest possible number of potential problems, and to secure the calculating capacity of the hardware.

The RoadLoad tool for studying region-to-region mobility, in its variant with departure points and destinations within the centroid, was used in the work by Borowska-Stefańska, Domagalski, and Wiśniewski [10] which focused on analyzing changes in flows of vehicle traffic induced by a flood (within the borders of the 100-year flood zone) in the Mazovian Voivodeship. Four variants of the research were conducted. In the first scenario, it was assumed that a flood does not occur, and all commuter trips are completed. This was the basic variant, which enabled comparisons of the results returned for all successive scenarios. The second variant included the occurrence of a flood throughout the territory of the Mazovian Voivodeship and the completion of all commuter trips. This scenario was intended to illustrate the initial phase of the natural disaster – the flood has already occurred, but no evacuation procedures have been commenced or implemented yet. In the third variant, it is assumed that the flood has occurred, no evacuation procedures have been commenced or implemented, but those who live in the disaster-stricken (flooded) municipalities will not be able to reach their workplaces, with the same applying to those whose workplaces are located in the afflicted area. The last, fourth, scenario is based on the assumption that there has been a flood, neither residents of the disaster-stricken municipalities nor those employees whose workplaces are located in the flood-afflicted area will be able to commute to work, and it has become necessary to evacuate the inhabitants of the towns and settlements within the flooded territory. It was also assumed that people are being evacuated to the nearest (timewise) municipality that has not been flooded. The changes resulting from the application of these successive scenarios were illustrated with the total time necessary to perform all commuter trips, the number of vehicles on the road network expressed in two-minute intervals, the number of episodes when the road capacity was exceeded in two-minute intervals (the number of vehicles exceeds the capacity in any given time period during the research), and the structure of the road network load, arranged by road class.

4. USING THE APPLICATION IN RESEARCHING POINT-TO-POINT MOBILITY

By and large, the use of the application does not entail any major methodological restrictions (except for the behaviour of homo economicus) as long as the study focuses on those trips for which the researcher has detailed data on departure points and destinations. Nevertheless, as far as such analyses are concerned, one must recognize the limitations regarding the hardware used to conduct them, as well as some interpretative restrictions whenever the study considers multi-sector trips across a vast area.

To present this, the article will demonstrate the manner in which the approach was used for the purposes of its co-author's doctoral dissertation. A shopping center was assumed to be the final destination, and all trips were to be completed precisely on time (during a peak-trading period) with regard to the theoretical travel time. Without scrutinizing numerous theoretical limitations of such a premise, the tool was used, in the dissertation, only to illustrate the most probable directions of mobility by car-borne shoppers of the aforementioned mall. For the purposes of the research presented in this article, the location of residents' homes and the corresponding number of available cars were estimated, which made it possible to encompass the detailed spatial distribution and load of departure nodes. Upon the performance of accessibility analyses, the distribution of trips to the shopping centres was determined (with the assumption that the number of potential customers is spread evenly between shopping malls of identical accessibility).

As a result of the aforementioned assumptions, it is possible to obtain both cumulative data and information on individual turns (Fig. 5).

In such a context (a precisely geolocated departure point and destination), the research results do not require the implementation of limitations related to any (occasionally) enormous aggregation which stems from the nature of the study on region-to-region mobility.

5. CONCLUSIONS

As in the case of other quantitative studies related to mobility, the presented tool is encumbered with numerous limitations, meaning that only a profound knowledge of the tool and its functioning guarantees its optimal use in research procedures. Although the application developed by the authors is not the only solution to be used in geographical studies to analyze flows (cf. such commercial software as Visum, Vissim, etc.) [19, 31, 34, 40], it does offer the undisputed advantage of monitoring the mobility of objects within the network in quasi-real time.

The presented implementation of Dijkstra's algorithm in the RoadLoad tool renders it possible to research and predict the course of phenomena with precisely stipulated departure points and destinations, as it demonstrates both spatial (cumulated values of network load) and time-spatial (network load at virtually any time) dimension of the phenomenon. It cannot be applied, however, without knowledge of the behavior of users of the transport system.

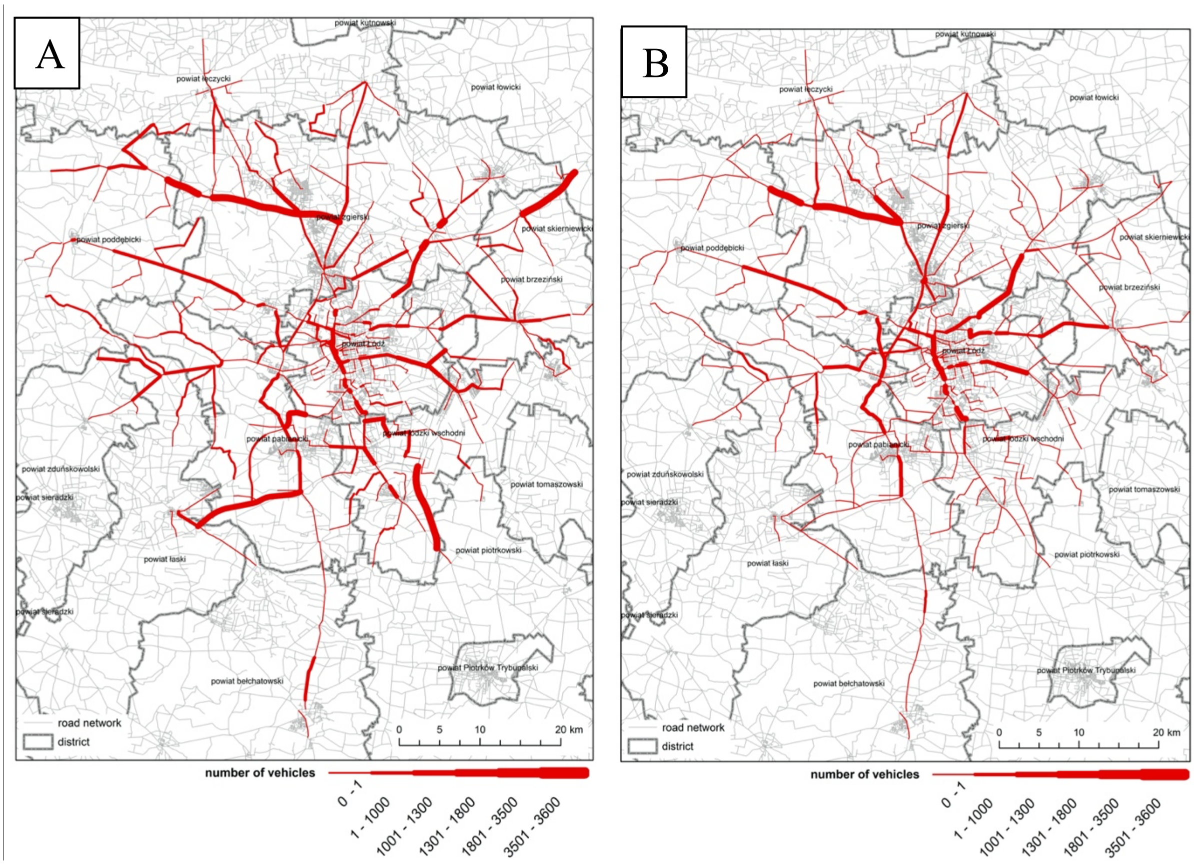

Fig. 5. The load of roads resulting from trips taken to one of the shopping centres: A – 5 minutes after departure; B – 10 minutes after departure

In the case of research based on imprecise information regarding departure points and destinations (e.g., grounded on aggregation data on territorial units), the presented tool may reflect reality only under the strict condition that the initial specifications have been properly formulated.

As far as the technical aspect is concerned, all the aforementioned analyses were conducted by means of the economic hardware and within a maximum time frame of 48 hours.

On the basis of the research presented herein and in view of the limitations of the method itself, the authors are developing the application, which, ultimately, is to enable the observation (in time and space) of trips taken by individual transport packages (a single vehicle or a group), as designated by the researcher.

Commercial software allows the introduction of many, though limited, attributes (for example VISUM). The author's application allows you to enter these attributes infinitely many and in a way specified by the researcher. As a result, the developed tool can be used not only to analyze networks in a state of equilibrium but also when disruptions occur, including non-typical events. For instance, it was used by Borowska-Stefańska, Domagalski, and Wiśniewski [10] in a study that shows the value of its practical applicability and proves that it can be used to determine the spatial volume and structure of changes in traffic density within a road network affected by a flood. Another interesting field where the tool can be used is observation of prognoses for traffic flows (their spatial volume and structure) for time intervals [11], which may facilitate preparation of plans and schedules for, e.g., a planned evacuation. What is more, the tool can also constitute a base for further development of an application that could be used to optimize processing time at a high level of accuracy, e.g., when heuristic algorithms are applied.

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