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GENERATING DATA IN UMP DATABASES TO PLANENERGY-SAVING ROUTES

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Abstract

In this article the model allowing finding energy-saving routes between two places in the navigation systems – for a cyclist's activity profile – was introduced. Preparing of the compiled routing maps for many kinds of navigation systems is possible by means of inclusion of model data into a database of UMP map project.

Introduction

Despite the fact that the satellite navigation systems where primarily made for car users, it is very common nowadays systems – so as to plan the optimal routes enabling to travel from one place to another – are also used by many other groups of users.

Finding an optimal route while analysing mainly its length (the shortest route) or the time of riding (the quickest route) does not show the amount of energy consumption needed to pass the given route in the appointed time. In normal conditions, in the traffic, there is invariably resistance of motion whose presence is not included in the satellite navigation systems. The most powerful shapes of resistance of motion are grade resistance (the gradient of the terrain) and air resistance.

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The following units / people might be interested in planning energy-saving routes: those with limited reserves of energy (electricity or rock gas-powered vehicles [such stations are a rarity], scooter users, bicycle users and pedestrians) and car drivers who make use of petrol only to pass through the given distance and who consider a velocity not as the force associated with the aerodynamics but rather the force connected with a traffic jam.

Among the abovementioned groups of people – due to limited energy resources – a group of cyclists, who while taking long distances would like to cover them in the shortest time, has been appointed for the analysis. The truth is that the process of planning a bicycle trip from Hel (Poland) to Rome (Italy) can be an enormous challenge, but thanks to the developed model it can be much easier.

The choice of implementation environment of the energy-saving routes model

The process of implementation of the model that allows planning energy-saving routes among the most popular satellite navigation systems such as TomTom, Igo, AutoMapa, MapaMap or Garmin is absolutely impossible. Such an assertion is supported by the abovementioned firms themselves. The firm Garmin expresses its interest in a broader circle of customers (Garmin – Manuals, on line: http://www.garmin.com/us/support/). Apart from a car driver profile, Garmin implements the following profiles of activity: a car, a motorcycle, walking, trekking, a bicycle, recreational cycling, mountain cycling, a cross-country vehicle, a lorry. Initially, a happy customer, enjoying the fact that an adequate system has eventually been found, arrives at a conclusion that it simply does not work properly. The truth is that it cannot work since it is based upon a conventional approach that allows using only specific road types designed for a given activity profile. An extra function of planning routes – minimisation of acclivity and descent – was even implemented but, as it has been demonstrated in the subsequent phase of the given model, it is not adequate for minimisation of energy while covering a distance.

The analysis has been aimed at GIS Open Source projects. Out of two solutions under examination – OpenStreetMap and UMP (PROCHOWSKI 2008) – the latter has been appointed, mainly due to a high quality of data of the road network in Poland but also to its creators' plan to incorporate newly generated model data into existent databases, out of which the compiled routed maps are generated so as to be used at a variety of system platforms.

The current area of research and the accepted constraints on the energy-saving routes model

The current area of research includes a lot of studies analysing the process of cyclist activity routes planning. The papers (RAITH et al. 2009, RENDALL et al. 2012) present good reviews of actual tends into this issue. The main area of research is focused upon a qualitative analysis of a roadway while designing a route using a range of criteria in order to produce a score for a friendly routing.

However, studies attempting to analyse the process of energy-saving routes planning are lacking. This study, therefore, for the first time implements the model of energy-saving routes planning. This model has been formulated so as to facilitate the implementation into UMP map system, employing the currently available data. The layer of the roads network for cyclists will be selected from the whole roads of UMP network (by means of determining road attributes) ensuring a safe cycling (a cyclist does not have to pay attention to high traffic volumes, narrow roads and the lack of cycle paths). The formulated model takes into account the fact that the energy consumption needed for covering the section of a route will by influenced only by: (1) unchangeable, natural earthly conditions (for example, the impact of wind, precipitation, the state of the road surface, temporary traffic barriers have not been considered), (2) the bicycle rolling resistance, and (3) the aerodynamic resistance of a cyclist-bicycle set.

Energy-saving paths in a diagraph

The problem of planning the quickest, the shortest or the most energy-saving path from one place to another can be identified while considering a common problem of finding the shortest paths in a digraph $G = (P, K)$ the set of vertices P (*node*) with a set of nodes and the weight function $w: K \rightarrow \mathbf{R}$, assigning edges of weight of real values. The shortest path leading from a node u to a node v in a digraph G is a path traced from u to v, characterised by the fact that its weight is the lowest. This problem, in view of the notion of weight, can be identified as a way of finding the least "costly" path from one node to another. Localisation of the least "costly" path for the sake of expense of energy allows introducing a notion of energy-saving path. The weight function has to be specified for this path. For the shortest route the length of edges constitute its weights; for the fastest one edge length ratios do that in relation to, mainly, a mean velocity assigned to road types (FLINSENBERG 2004).

An object in motion is under the force that is a resultant of forces propelling and decreasing its motion. In terms of energy-saving process, it is essential to consider an influence of decreasing forces inhibiting motion that can be graphically shown in the shape of resistance to motion F_o. The force that has moved an object has produced work. And this work is assessed in relation to the time needed for its accomplishment. A velocity of an accomplishment of work specifies the power of unit (an engine, a person) P. An object has to have a dose of energy tantamount to amount of work so as to accomplish this work taking a specified route. It is easy to observe that a dose of energy needed for an accomplishment of work, while taking a route, has to be connected with the power of an object P. Accordingly, constant mean velocities, taken into consideration in context of the fastest routes, are replaced by the constant power P_c, that an object is certain to be supplied with in an existing environment while taking a specified route and adjusting a velocity of ride (more powerful resistance = a slower velocity of motion supported by a specified gearing in a power transmission system). A velocity of an object taking a specified route at constant resistance F_o, is expressed by means of the relation:

$$v = \frac{P_c}{F_o}$$

The weight of an edge at length d_i in a diagraph G expresses the time of passing a given route subject to resistance of motion, that is to say $w = \frac{F_o d_i}{P_c}$. For a planned route a sum of weights signifies the time in which a model object passes a given route maintaining the constant power P_c. For that reason the shorter time signifies the lower consumption of energy.

While planning the shortest routes are used road maps. On the strength of a map, in order to implement algorithms that allow planning an optimal path, a diagraph G must be employed. Edges of a diagraph are made of road segments – polylines that include, among others things, coordinates of points of a road curve, length, a road type, the name of road, an acceptable direction of traffic. The majority of those attributes is essential while planning routes. Nodes of a diagraph are marked in physical places of polyline intersections (e.g. the physical intersection of roads under and over a viaduct does not exist) or in places of connection of two polylines having different attributes (e.g. a soil-surfaced road entering an asphalt road).

A model of a cyclist's ride

Shapes of motion resistance

While in motion a cyclist has to overcome main resistance F (ORZEŁKOWSKI 1998) that influences the energy consumption of motion:

resistance of a road

– rolling resistance (apart from frictional resistance in bearings and gearshifts that are present while in motion)

– height difference resistance (+acclivity, -descent)

aerodynamic resistance

Model data are as follows:

M = 75 kg – the weight of a model cyclist,

m = 13 kg – the weight of a model bicycle MTB,

G – a combined weight of a cyclist and a bicycle,

V_c = 25 km/h – a velocity that a cyclist has to maintain, in a flat terrain, overcoming other forms of motion resistance,

P_c – the constant power that a cyclist has to generate while passing an entire route,

g = 9.81 m/s^2 – gravitational acceleration,

Weather conditions: no wind, atmospheric pressure of 1 standard atmosphere (atm), air temperature equals 20°C.

Rolling resistance is caused by the cooperation of a bicycle wheel tires and a road surface. The total power of rolling resistance F_t, acting on the rider-bike system is directly proportional to the weight of the system, and takes the form when riding on a road inclined at an angle α:

$$F_t = f_t \cdot G \cos\alpha = f_c(M + m) \cos\alpha \tag{1}$$

where f_t means the total rolling resistance coefficient. It depends mainly on a type and size of tires, tire pressure, speed (a velocity impact is not significant for the speed at V_c) and a type of surface.

Off-roading, on unpaved surfaces, requires overcoming much larger forces of rolling resistance than riding on hard surfaces. Approximate values of a rolling resistance coefficient (Garmin – Manuals, on line: http://www.garmin.com/us/support/) depending on a type of surface are shown in Table 1.

Tabele 1

Rolling resistance coefficients for a surface from UMP project where a cyclist can move

A type of road in UMP project	f_{UMP}	A type of surface	Values of a coefficient f	
			from	to
0×3, 0×4, 0×5, 0×6, 0×7	0.015	asphalt and concrete surfaces	0.010	0.015
0×*a*	0.050	hard soil-surfaced roads	0.030	0.100
Not considered	0.150	wet gritty roads	0.080	0.150
0×16, {4×4}	0.100	hiking trails, firm ground, sand, pebbles	0.030	0.150

f_{UMP} – set value of rolling resistance coefficient for road types in UMP project.

On the basis of ERNEST (2010) it is accepted that f_c, on the assumption that $f = 0.015$, for the asphalt road surface. In consideration of a road type in forms of rolling resistance taken from UMP project, an applied dependence on a rolling resistance coefficient is gained:

$$f_c = 0.035 + f_{\mathrm{UMP}} \tag{2}$$

Terrain height difference resistance – resistance of a hill, acting when driving uphill, is the main component of road resistance which, unlike rolling resistance is variable in different terrains and significantly affects an energy expenditure needed to pass through that segment of a route. Assuming a constant slope of a road surface, a positive angle α, as a slope of acclivity, and a negative angle while descending – the resistance force directed parallel to a road surface can be worked out from the formula:

$$F_h = G \sin\alpha = G \frac{\Delta h}{\sqrt{\Delta h^2 + d_p^2}} \tag{3}$$

with a height difference Δh between the end and the beginning of a segment of a road with a horizontal length d_p. For example, for the section of the road {(N49.47399 E20.55720), (N49.47843 E20.55255)} a 0×7 type, a height difference equals 60 m, $d_p = 580$ m, and for that reason $F_h = 100$ N.

While combining the power of terrain height difference and rolling resistance, one can employ the concept of *road resistance* (PROCHOWSKI 2008):

$$F_d = F_t + F_h = Q(f_c \cos\alpha + \sin\alpha) = Qf_\alpha \tag{4}$$

where f_α is the coefficient of road resistance. It allows revealing, globally, the impact of a road on the following system: a cyclist – a bicycle.

Aerodynamic resistance – the force of air resistance F_p is determined by means of the formula (PIECHNA 2000):

$$F_p = c_x A \, \rho \frac{v^2}{2} \, a_e v^2 \tag{5}$$

where: A – the frontal projection of the face of a bicycle and a cyclist, in the position occupied while driving; ρ – density of the air, c_x – the aerodynamic resistance coefficient, treating quantitatively aerodynamic properties of a cyclist on a bicycle and a bicycle itself; $v \left[\frac{\mathrm{m}}{\mathrm{s}}\right]$ – the relative velocity of a cyclist in relation to the air.

On the basis of, among other things, the research carried out by the author of the study: $\rho = 1.2 \, \frac{\mathrm{kg}}{\mathrm{m}^3}$, $A = 1.5 \text{ m} \cdot 0.3 \text{ m} = 0.45 \text{ m}^2$, $c_x = 0.98$ (a top coefficient has been accepted, corresponding to the given shape of a cyclist and a typical sport outfit. It differs significantly from a professional cyclist coefficient, which can on average be $c_x = 0.25$), and for that reason

$$F_p = a_e \, v^2 = 0.02 \, v^2 \, \frac{\mathrm{km}^2}{\mathrm{h}^2} = 0.2646 \, v^2 \, \frac{\mathrm{m}^2}{\mathrm{s}^2} \tag{6}$$

At a speed of 10 km/h, the air resistance force equals 2 N. The process of doubling of a velocity makes the resistance force four times bigger, for a velocity of 25 km/h it takes the value of 12.5 N, the equivalent resistance of ascension during the acclivity on a surface inclined at an angle of circa 0.8° to the level.

The power increase of strength of air resistance can be illustrated by means of an example (ERNEST 2010), demonstrating that with an uninhibited descend on a road inclined at an angle of 5°, a cyclist is able to reach a maximum velocity of 70 km/h, at that point the equilibrium between road resistance and air resistance occurs. The air hinders one's motion, preventing a cyclist from reaching a higher velocity.

Windy weather conditions

A violation, adopted in section *Shapes of motion resistance*, of the assumption about a windless weather can completely change the fact of the energy consumption of a planned route. Assuming a wind velocity higher than 0, parallel to the direction of motion v_α, with a positive value for the opposite wind and a velocity of a cyclist in regard to the ground v_g, we will achieve the previously introduced force of air resistance in the following shape

$$F_p = a_e\, v^2 = a_e\, (v_g \pm v_2)^2 \tag{7}$$

Maintaining a velocity of 25 km/h against the wind of, e.g., 30 km/h requires a cyclist to overcome five times the given resistance, namely 60 N. It is difficult to meet the assumption of maintaining a constant power of a cyclist.

Will it be ever possible to include the strength and direction of the wind in the model? Routable maps taken from UMP project are compiled daily and the possibility of taking into account those pieces of information is recognised while using the available map of wind gradient. The data would thus have only one-day validity. But there are other problems, such as the multiple-day routes and the fulfilment of the assumption that the wind strength and direction will be constant all the time. This assumption will never be fulfilled. Hence, the justification for the assumption of windless weather conditions, and only under such conditions the energy-saving routes in UMP will be planned.

A model velocity of a cyclist

Motion resistance affects an energy expenditure of a cyclist, essential to pass the given road at a certain time. Depending on the power of resistance, a cyclist passes equally long sections of a road reaching different velocities because a body's capacities, while providing more power to maintain a constant velocity at high resistance power, are very limited, unlike in motor vehicles case. Therefore a cyclist, on a given route, cannot maintain a constant velocity – only the constant power. The value of the constant power is determined for a middle class cyclist who along the whole route can maintain, on a model MTB bicycle, a constant velocity v_c, in a flat area, using an asphalt road ($f_c = 0.05$), beating other forms of motion resistance:

$$P_c = Fv_c = (F_t + F_p)v_c = 119 \text{ W} = 0.162 \text{ KM} \tag{8}$$

A velocity in km/h which must be maintained so as to achieve the power P_c, is a real root v_1 of an equation:

$$P_c = 3.6^{-3}\, a_e v^3 + 3.6^{-1}(F_t + F_h)v$$

$$v_1 = 3.6\left(\frac{\sqrt[3]{2}(F_h + F_t)}{\sqrt[3]{27a_e^2P_c + \sqrt{108a_e^3(F_h + F_t)^3 + 729a_e^4P_c^2}}} + \frac{\sqrt[3]{27a_e^2P_c + \sqrt{108a_e^3(F_h + F_t)^3 + 729a_e^4P_c^2}}}{3\sqrt[3]{2}a_e}\right) [\mathrm{km/h}] \qquad (9)$$

The following chart shows the relationship v_1 between a velocity and the angle of the terrain gradient.

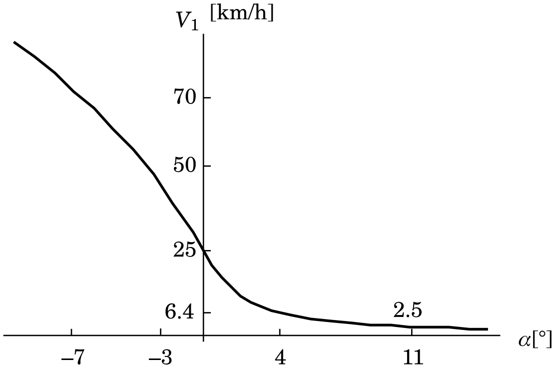

Fig. 1. Reliance of a velocity of a cyclist on terrain gradient for (f_c = 0.05)

For an acclivity at 11° gradient, for a cyclist to maintain the power P_c, one has to move slowly at 2.5 $\frac{\mathrm{km}}{\mathrm{h}}$. Riding below that velocity can cause a problem in maintaining the balance of a cyclist on a bicycle. In such a situation, one has to lead a bicycle; keeping up the pace of a walk at 2.5 $\frac{\mathrm{km}}{\mathrm{h}}$ with a bicycle is no longer any problem. It is assumed that a velocity equals:

$$\hat{v} = 2.5\,\frac{\mathrm{km}}{\mathrm{h}} \text{ for } v_1 < 2.5 \qquad (10)$$

While a cyclist is descending, the situation is reversed. At a gradient of $\alpha = -3$, a cyclist, can achieve a velocity of 50 $\frac{\mathrm{km}}{\mathrm{h}}$, and for a terrain descend gradient –7 a velocity of 70 $\frac{\mathrm{km}}{\mathrm{h}}$. The last value is determined as a final one; above that velocity cycling becomes dangerous. A cyclist can have problems maintaining so high velocities on a curved road where the centrifugal force $F_r = \frac{(m + M)v^2}{R}$ occurs (with a momentary curvature radius of a road R). The maximum lateral force cannot be higher than the force of friction. The maximum velocity of a ride at the arc, in view of slipping wheels, can be calculated be means of the formula [0]: $v_{\mathrm{max}R} = \sqrt{\mu g R}$, where the tyre friction coefficient for a road μ takes values in the range from 0.2 for 0×a type to 0.8 for 0×1–0×6 types. Determination of a momentary radius of curvature for a road, marked with a string of points forming a polyline, is an easy analytical geometry task. However, in order to determine the maximum velocity of a cyclist, along the given route, it is not enough to limit only to $v_{\mathrm{max}R}$, which, at times, is not sufficient to limit the maximum velocity on the route similar to a straight line.

The solution would be usage of – used in many GPS navigation systems – the table of mean velocities which in line with a model solution will be used as the table of impassable velocities on specified road types (sample data are shown in the table 2).

Tabele 2

Impassable velocities of a cyclist on specified UMP road types

UMP road type	Maximum velocities
0×3,0×4,0×5	70
0×6	60
0×7	40
0×a,0×d	30
0×16	25

Justification for adopting such an approach lies in considering the fact that while designing a specific road type, designers must take into account velocities of moving vehicles; the process is reflected in appropriate profiles of road types.

A ride of a model cyclist – each cyclist passes through the given route differently, handling the various power distribution over time of a ride (FRIEL 2004). A cyclist generally attempts to maintain a steady velocity and does not pay attention to the fact that its continuation in the field with a slight assent causes more power consuming. A cyclist – the source of move – has different characteristics of the power delivery than a mechanical engine. Its uneven distribution over time leads to the fact that an initial fast driving, at the further section of the route, may be reduced and frequent stops for regeneration of energy providing the specific power will be needed.

A model ride of a cyclist is different. It relies on the process of maintaining, while driving, a constant power, not a velocity (in a flat area a constant velocity equals 25 km/h). The time of crossing an entire route t_t consists of a travel time t_j and a waiting time t_p, needed for the recovery of energy. Depending on the condition, a model time of a ride is increased with a time t_p, testifying for a cyclist;s physical preparation. A model ride of a cyclist is characteristic of a long-distance cyclist who knows how to make a uniform distribution of force along an entire route, and for those people, these routes will be energy-saving.

For example, if a cyclist knows that he/she can maintain in a flat area a velocity of 25 km/h, by the time t_j = 3 h, covering thus 75 km (keeping a constant power all the time), then in the area of assent 3^o in time t_j, and riding at a model velocity of 8.2 km/h, a cyclist will cross 24.6 km and a height difference of 3930 m. A future problem for a cyclist will be to assess how fast he/she needs to cross a section of a route because the navigation devices available now do not perform this function.

Implementation of a model in UMP project

UMP road network

UMP with its reach minutely models the Polish road network. The project covers the area of the whole world but its coverage is not as extensive as an analogous project OpenStreet.

A spatial database of UMP project is composed of PFM (Polish Format Map) text files (KOZICKI 2009), shown in view of the location and types of objects.

PFM has been developed by the author of the program cGPSmapper in order to create compiled maps used in Garmin receivers. The program has allowed making generalisations about the format by adding new data which will enable creation of compiled maps, used in various systems and applications (such as Android, iPhone, Windows Mobile, Symbian, Navitel, Garmin, WWW – http://mapa.ump.waw.pl, civic navigation http://jakdojade.pl). An extensive list of versions and applications can be found at: http://ump.fuw.edu.pl/wiki/Wersje.

The objects of road network used by a cyclist and shown in PFM format comprise sections entitled `polyline.` Below you can find an example of an entire Piramowicz Street in Nowy Sącz 0×5 type (a complex road). The coordinates of the points of bends of the street, expressed in degrees in GPS system (width, length), will be taken only from 0 level, from `Data0.`

```
[POLYLINE]
Type = 0x5
Label=Piramowicz
EndLevel=2
Data0=(49.59984,20.68605),(49.59922,20.68718),(49.59913,20.68728),
(49.59905,20.68733),(49.59849,20.68763),(49.59839,20.68781),
(49.59832,20.68805),(49.59830,20.68833),(49.59833,20.68849),
(49.59836,20.68863),(49.59860,20.68915)
Numbers1=0,O,1,7,E,2,20
Numbers2=6,O,9,9,E,22,24
Plik=src\NOWY_SACZ.ulice.txt
[END]
```

In the `polyline` section you can add, after having arranged for it with the authors of UMP, new attributes that are necessary for implementation of a bicycle routing, based on the criterion of minimising the energy. For each `polyline`, object where a cyclist can move, it will be necessary to generate data for the `SpeedBike`, attribute with a model velocity of a cyclist riding in the direction from the first to the last point forming a polyline and in the opposite direction (e.g. `SpeedBike=10.2, 50.1` – a model cyclist, in the direction of moving, rides with a velocity of 10.2 $\frac{\mathrm{km}}{\mathrm{h}}$ (acclivity), and in the opposite direction (descend) with a velocity of 50.1 $\frac{\mathrm{km}}{\mathrm{h}}$). In order to achieve an adequate fit of a model to the actual terrain conditions – which may significantly differ from the assumptions – prevalent in particular road types (e.g. road signs reducing a velocity because of local dangers may occur, or for 0×16 type, while descending, it will not be possible to reach a high model velocity in view of a surface that prevents an uninhibited descend) it is necessary to introduce `SpeedBikeFix`, attribute that encodes the same velocity of a cyclist. Once the attribute is placed in `POLYLINE` section, `SpeedBike` velocities are ignored, giving way to real values.

A numerical terrain model – NTM

In order to determine F_h, resistances caused by terrain height difference, it is necessary to specify a terrain profile for each polyline. Prevalence of electronic computing technology has been responsible for a widespread use of, in a similar type of engineering tasks, numerical terrain models that mathematically portray a landform.

A numerical terrain model (NTM) of the Earth, created jointly by NASA and Japan, has been used to generate the data. It was created out of over a million stereomicroscopic pairs of images, collected by the Japanese ASTER (Advanced Spaceborne Thermal Emission Reflection Radiometer), the instrument located aboard the Terra satellite. NASA and the Japanese Ministry of Economy, Trade and Industry (METI) have developed a set of data which can be downloaded from the Internet for free.

The points of this terrain model comprise a regular grid of 30×30 m squares. For the area of Poland data has been downloaded from the website: http://gdex.cr.usgs.gov/gdex/ using ESRI GRID ASCII format, in seven parts, due to introduced restrictions on a single use download. ASTER Global DEM V2, ArcAscii, Projection has been chosen:

```
GEOGCS["GCS_WGS_1984",DATUM["D_WGS_1984",SPHEROID["WGS_1984",
6378137,298.257223563]],PRIMEM["Greenwich",0],UNIT["Degree",0.
0174532925199433295]].
```

Below there is a heading of one of downloaded spheres in ESRI GRID ASCII format:

```
ncols         16690
nrows         6407
xllcorner     18.984375000000
yllcorner     48.779314138406
cellsize      0.000277784901
NODATA_value –32768
284 281 279 276 275 277 282 281 ...
289 296 306 316 325 313 308 303 ...
................................
```

In order to obtain data in one rectangular XY set, NTM ellipsoidal coordinates and polylines (`Data0`) have been transferred to the 1992 National Coordinating Centre using the formulas given in SNYDER (1987) for the Transverse Mercator map projection with accepted parameters: scale on the midpoint meridian $m_0 = 0.9993$, the midpoint meridian $\lambda_0 = 19°$

Knowing the coordinates of the nodes of the grid of NTM squares, the height of any point $P1(x,y)$, located inside the *ABCD* square (fig. 2), can be calculated by means of the following formula:

$$H_{p1} = r^{-2}[(r - \Delta x)(r - \Delta y)H_A + \Delta x(r - \Delta y)H_B + \Delta x\Delta y\ H_C + (r - \Delta x)\Delta y\ H_D]$$

$$\Delta x = x_{P1} - x_A; \quad \Delta y = y_{P1} - y_A \tag{11}$$

where r is the length of the grid square; H_A, H_B, H_C, H_D being corner heights of its nodes.

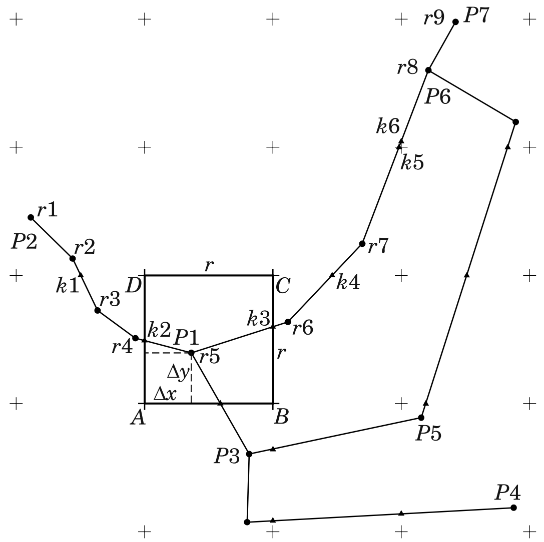

Fig. 2. UMP project road network with NTM square grid

An appointment of model velocities along any segment of a route

Let us consider a representative polyline taken from figure 2, with a known road type t, appointed by the points $r1$, ..., $r9$, whose coordinates have been previously transformed into the "1992" rectangular set. The polyline crosses the sides of the grid of NTM squares at the points $k1$, ..., $k6$ whose coordinates are likewise located in the "1992" set. As a result of crossing of the polyline through DTM, the height is assigned to each ri, ki point using the formula (10), creating a profile of a road out of ordered points, possessing now three coordinates (x, y, h):

$$S = (r1, r2, k1, r3, r4, k2, r5, k3, r6, k4, r7, k5, k6, r8, r9)$$

For each section of the profile $|s_i, s_{i+1}|$ $(i = 1, ..., \overline{S} - 1)$ with a length d_i, a velocity is appointed using the dependence (9): v_{1i} – in a consistent direction and a return direction $|s_{i+1}, s_i|$, namely v_{i1}. The final values after considering the dependence (10) and the impassable values taken from table 2 are expressed by means of symbols $\hat{v}_{1i}$, $\hat{v}_{i1}$. The attribute value `SpeedBike` will be appointed from the following dependence:

$$\texttt{SpeedBike} = \frac{\Sigma d_i}{\Sigma \frac{d_i}{\hat{v}_{1i}}}, \frac{\Sigma d_i}{\Sigma \frac{d_i}{\hat{v}_{i1}}} \tag{11}$$

While creating linear objects in UMP project, an economic principle of drawing maximum long objects possessing fixed attributes (a label, a type, unidirectionality of a road, the level of visibility on a map, traffic restrictions – `ForceClass`) has been adopted. This leads to a necessity of extension of SpeedBike attribute value on account of the fact that after the road network from figure 2 has been transformed into the graph (fig. 3), determination of weights on the edges between nodes will be impossible: $P2P1$, $P1P6$, $P6P7$ weight for $P2P7$ edges.

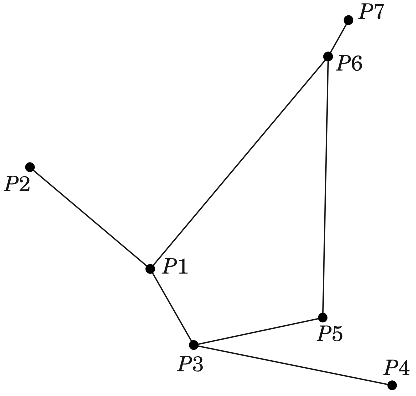

Fig. 3. The graph of road network, made from a section of UMP project, presented on figure 2

Prior to the process of determination of model velocities, a generating program finds nodal points, and along every section from a node to a node it sets values from (11). The process of encoding values on attributes, for polylines with i points, is as follows:

```
SpeedBike=5,18,30;8,10,45;9,25,25
SpeeBikeFix=8,12,21
;-------------------------------
SpeedBike=5,18,30;8,10,45;9,25,25
SpeeBikeFix=5,12,16;9,15,20
```

The above entry signifies that starting from the point 1 to 5, a model velocity of a cyclist is 18 and 30 in return direction; between points 5–8 it is 10 and 45 respectively, and ending at the 8–9 edge with the velocity of 25, that is on the flat terrain. The introduction of actual values by `SpeeBikeFix` attribute is not necessary for all edges. The abovementioned entry means determination of the velocity up to the point 8, from a nodal point located directly in front of it, namely the node 5.

Conclusions

The assignation of bicycle paths, based on the conventional models used in routes planning process for motor vehicles is, in the area of diverse terrain shapes, difficult to accept. In this paper, on the example of the activity profile of a cyclist, the model has been developed, enabling the process of planning of energy-saving routes that can be effectively used by various entities whose energy resources are limited due to physical limitations or rarity of places where the refilling of energy is possible. The given model takes into account the fact that the consumption of energy needed for crossing the given section of a route is affected only by: unchangeable, natural conditions of the earth, a bike rolling resistance and aerodynamic resistance of a cyclist-bicycle set.

Our choice of the cyclists – treated in the given article as a model group – was made in view of the desire to change the prevailing belief among them that the satellite navigation systems are unsuitable while planning optimal routes. A deeper analysis of the problem allowed us to find the causes of this situation. The shortest route in a corrugated terrain that could even be the fastest one – may demand from a cyclist more effort and time than an energy-saving route which may even be 5 km longer than the shortest route, the one of about 60 km. Car drivers do not need to pay greater attention to energy consumption of a route because they can dynamically increase the power input, maintaining a constant velocity, regardless of air resistance. Furthermore, it is hard to show competently what profit they could have as far as fuel consumption is taken into consideration while taking an energy-saving route. A middle class cyclist, however, has limited power resources at the level of tenths of a metric horsepower (KM) that do not allow a cyclist to maintain a constant velocity while riding in a "sinuous" terrain. Hence, the problem of usability of car navigation arises while planning routes for units with a low range of the power intake and a necessity to implement the developed energy-saving routing should be highlighted.

The developed model is set up to be implemented into UMP map project that allows one to add the necessary model data to your databases and create compiled maps with an energy-saving routing for a specific system platform (e.g. Garmin, Navitel or those with Android operating system, Symbian, Windows Mobile).

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