A Tool For Active FLEET Management and Analysis of Activities of a Snow PlowING and a Road Salting Fleet

Rok Strašek, Tina Vukasović

Abstract - Current economic crisis combined with increasing fuel costs rises awareness that the logistics represents a large portion of costs in value chains, and hence increases the interest of modern companies for investments in research and development of specialized fleet optimization tools. We present a new tool and a methodology that enables the end-user to carry out logistic research and optimization in a relatively complex logistic system for snow plowing and road salting. The tool incorporates management of GIS and network data, monitoring of GPS tracked vehicles and communication layer, together with a set of tools for planning, analysis and optimization of routes. The system also enables remote navigation through on-board computer connected to the application. We present a case of analysis on a particular snow plowing operation.

Keywords- transportation, fleet management, logistics optimization, operations research, snow plowing, digital maps, GPS

1. INTRODUCTION

A logistic system dealing with road transportation activities typically consists of a fleet of various vehicles (with specific functionalities, parameters), logistic processes (depending on the purpose of the system), a road network to operate on and a system for vehicle tracking (usually GPS normally combined with bi-directional communication layer for data transfer). Motivation for investments in research and development regarding system's operations depend on actual economic situation, where the level of information technology supported in the system plays a significant role. A common setting includes integration of company's information system with a service offering up-to-date digital maps (matching the current state of the road network) and a real-time GPS (Global Positioning System) tracking service, provided that the tracking devices are installed in all vehicles

of the fleet. In this paper we present an application of an advanced prototype tool developed in a research project for the purpose of supporting activities of snow plowing and road salting.

Manuscript received August 16, 2012; revised September 17, 2013. The work presented in this paper is a result of a part of the research project L5-4282(A) "Mathematical modeling of processes and computerization of the logistics system", financed and supported by Slovenian Research Agency (ARRS).
Professor, dr. Rok Strašek Faculty of management, University of Primorska, Koper, Slovenija (e-mail: rok.strasek@um.si).
Assistant professor, dr. Tina Vukasović, International School for Social and Business Studies, Mariborska cesta 7, SI – 3000 Celje, Slovenia; University of Primorska, Faculty of Mathematics, Natural Sciences and Information Technologies, Glagoljaška 8, SI-6000 Koper, Slovenia, (e-mail: tina.vukasovic@mfdps.si)

2. TECHNOLOGY AND DATA

The main challenges with digital maps (so-called GIS - Geolocation Information System) include providing up-to-date data in the geometric layer (the base level of GIS, containing roads, buildings etc.), topology layer (where junctions, crossroads etc. are identified), as well as in other information layers, which are specific for a particular logistics system (for instance direction of roads, width of roads, critical points, pavements, additional infrastructure, elevation, speed limits, distribution plans, etc.). Early in the research process, we have determined that the company contributing in the research had capabilities to set up their own GIS network data layer containing geometric objects as road sections, enriched with attributes relevant to their activities and needs. We have also identified that standard GIS tools provide satisfactory functionality for geometric object representation, but usually do not provide functionality for topological information encoding (connectivity, behavior at crossroads that depend on traffic regulation, one-way streets etc.). Our tool enables loading of existing GIS layers and orthophoto layers, and provides advanced capabilities of editing enhanced GIS layer by adding topological information. We use two layers, one for point objects representing crossroads and road junctions, and other road section layer with line string geometric objects representing road sections. Both layers are integrated through the well-known mathematical structure called "graph".

In our case we have a fleet of vehicles, which are equipped with GPS tracking devices communicating their location using wireless communication layer to the server every 15 seconds. We have developed our own robust algorithm for projection of GPS location samples to the GIS network, considering proper topology. Thus, we can track vehicle movements on our own network, which we can regularly update. This is particularly important when we want to use fully up-to-date network containing all road sections, knowing which road sections are available and which are blocked for some reason at anytime. Commercial map systems (e.g. TeleAtlas - http://www.teleatlas.com, Navteq - http://www.navteq.com) do not allow this level of flexibility for a reasonable price.

The GIS road network is also used as a base for snow plowing and road salting planning. Based on the experience in past years, the road sections that have to be plowed and/or salted are partitioned into groups, which are called snow-plowing plans (or simply "plans"). Each road section in a plan has custom requirements for plowing and salting - how many times it has to be considered (processed) in each of the (allowed) directions. Plans are established in advance and drivers are trained to handle particular plans. Each plan's length is around 20km. Driver's skills and knowledge of the plan contribute to optimality of routes, where in particular one has to have in mind possibilities of special events. Special events include blocked road sections or wrongly parked cars preventing plowing, which occur quite often during the snow plowing service, etc.

Our working plan is to further develop the system to enable real-time progress monitoring and identification of special events or anomalies, which result in temporary blocks of particular road sections and prevent carrying out of the fleet activities, thus changing their route plans.

3. ANALYSIS

At this stage of the project our focus is to establish what is the real potential of optimization of routes. In each snow plowing and salting operation a particular vehicle is assigned a plan that has to cover. The vehicle starts from the base where it loads the salting material, than it covers the plan in one or more loops, each time returning to the base for reloading salt or fuel. Usually the plan is covered by one to three loops. We have analyzed several actions of particular vehicles and plans, and tried to optimize them by heuristic algorithm developed within the research team. Our finding is that there are in general gaps of possibilities for optimization for 10-35% regarding the total distance traveled in kilometers. Considering the quite often occurrences of special events that require changes of route covering plans, the gap can become more narrow and percentages usually get lower. This gap can be exploited in order to optimize the plowing and salting process by introducing route optimization together with remote vehicle navigation through on-board computer. We present the methodology of our analysis, which will be shown on a plan no.1 given in Figure 2. The vehicle used will be denoted by ID number 784.

As we have noted, each operation consists of several loops which we shall analyze through the following indicators. The figures Figure 3, Figure 4 and Figure 5 show the visual statistics of the operation. Further, the following performance indicators are shown in Table 1.

- **No. of loops** - the number of loops.
- **Beg. time -** time of the beginning of a loop.
- **End. time** - time of the end of a loop.
- **Duration** - duration of a loop.
- **Km plan** - number of kilometers in the loop driven over the plan.
- **Km eff. plan** - maximal number of kilometers that could be considered at processing of the plan; for instance, if a section of length 100m has to be processed twice in one direction and once in other, but in total we have three traversals in one direction and four traversals in another, only two traversals plus one in opposite direction are counted (thus 300m all together).
- **Km out. plan** - kilometers outside the plan.
- **Total len.** - the total length of the plan (calculated with multiplicity - for instance, a section of length 100m that has to be processed in both directions contibutes 200m to the total length of the plan).
- **Km total** - total number of kilometers for the loop.
- **Eff. % cover** - effective percentage of coverage: calculated as **Km eff. plan/Total len**.
- **Len. % cover** - the length traversed over the edges in the plan in the loop, calculated as **Km plan/Total len**. In comparison to Ef. % cover, this indicator indicates the ratio of unnecessary traversals to necessary traversals.
- **Km cum. plan** - cummulative sum of traversed kilometers over all loops from the beggining to the end of the current loop.
- **Km cum. eff. plan** - effective coverage of the plan over all loops from the beginning to the current loop. While **Km. eff. plan** measures effective coverage of each loop like it is covered separately without considering previous loops, this indicator considers cumulative coverage of all previous loops (for instance, if a section has to be processed two times in one direction and this was done in some of the previous loops once while in current loop this is done three times, only one traversal - needed for completion - is counted here).
- **Km cum. total** - total cumulative number of kilometers (sum of current and previous loops).
- **Cum. % cover** - total cummulative coverage. **Km cum. km plan/Total len*100**. Measures what is the ratio of all killometers from the starting loop to

the current loop towards the length of the plan. Note that this percentage can be 300% but plan may not be completed yet.

- **Eff. cum. % cover** - actual coverage in percents of the plan: **Km cum. eff. plan/Total len*100**.

4. OPTIMIZATION

Optimization of the operation is carried out by a heuristic search algorithm which uses local optimization minimizing the objective function **Km cum. total.** Heuristic algorithms are usually not exact, but in practice give quite good solutions. We have used not to complicated local search run based on some ideas from similar Vehicle Routing Problem (see [1]), running on several instances in parallel. No metaheuristics are used in this case. Even with this relatively simple heuristics we can achieve better results, which is no surprise. Inputs for the algorithm are:

- a plan with requirements for processing for road sections in each direction
- a base point from which loops start and in which loops end
- maximal distance for salting; we assume in the optimization model, that the intensity of salting is all the time the same and that the salting is being done at the same time as plowing. Using up all or most of the salting material is a reason to break the loop and return to the base for refilling.

The optimization model assumes that all priority 1 sections have to be processed before processing of any priority 2 section has started. Beside this limitation, any section which is traversed both directions for the required number of times is counted as the processed. Additional assumption is that the plowing speed in a loop is 10 km/h while the driving speed in the loop outside the plan is 30km/h. We do not incorporate waitings in the road junctions (for instance traffic lights). These assumptions make the plan not time-realistic, but considering the distance traveled and considering the detail of data incorporated into the maps, the results are traversed-lenght-realistic. The parameter maximal distance for salting could be determined in various ways, but the most realistic would be averaging measurement during long term operation. For our purpose we have assumed that the indicator Km. eff. plan for the first loop, when the loop is carried out without any special indicates the closes estimate. To be on the safe side we take 90-95% of that value for the maximal distance for salting. In the demostration case we have taken 12 km (see 12,9 km in Table 2)

The result shows that the processing of the complete plan (instead of only 75,7% of it as in the real case, see Table 1) takes about 20% less traversed length (72,8 km instead of 94,0 km). Of course this is with the assumption that no special events occur during the processing. But if instead of the requirement for processing the whole plan we require processing of exactly those road sections that have actually been processed, we get even better results (see Table 3. Here the savings increase to more than 35%.

Similar situation we have encountered when analysing other plans. Considering this facts, we believe that implementing the system that could carry out real-time plan optimizations based on the information collected from the field (blocked roads, missed road sections, accidents, brakdowns etc.) combined with the mandatory central navigation through on-board computer wirelessly connected to the base application, would easily achieve optimizations in range of 10%.

5. FURTHER WORK

We are currently implementing and testing remote navigation system through communication with on-board devices. We have tested the algorithm also in the setting where several vehicles have to share several plans. Since this situation happens quite rarely (for instance when a vehicle breaks down and instead of sending substitute, other vehicles that have assigned their own plans get additional assignment of the parts of the remaining plan) we currently do not have large enough (trusted) set of testing data. In such rare cases the remote navigation would also be a good solution, because usually the drivers assigned to the failed plan do not have so good knowledge about that plan in comparison to the knowledge of the plan that have been regularly assigned to. Remote navigation could clearly help in minimizing the information management complexity in such cases thus making decision support much easier.

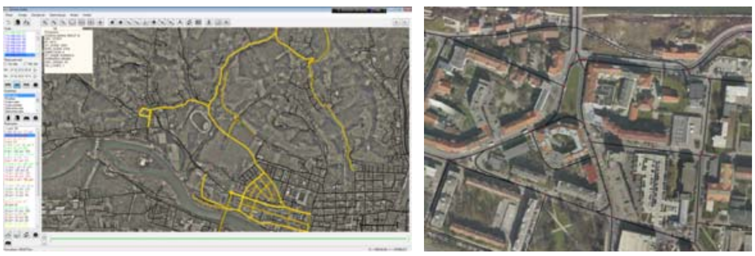

Figure 1: Left: a screenshot of the application. Right: GIS road network represented by two layers of geometric objects; the point objects - representing junctions, which are nodes of the underlying graph are colored in red, while black are the lines representing the road sections.

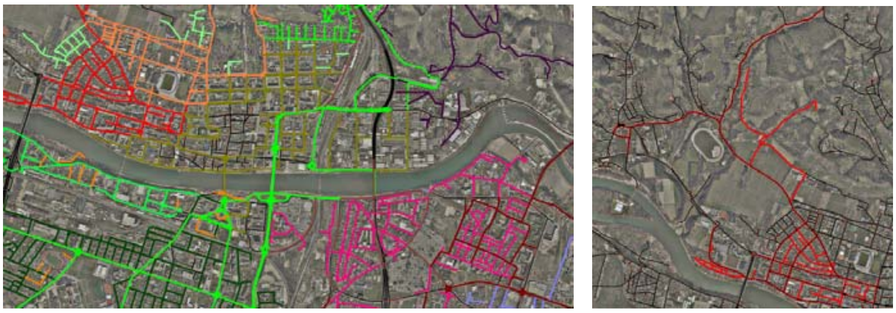

Figure 2: Left: plowing plans are represented by different colors. Right: plan no.1 is used to demonstrate analytic methodology.

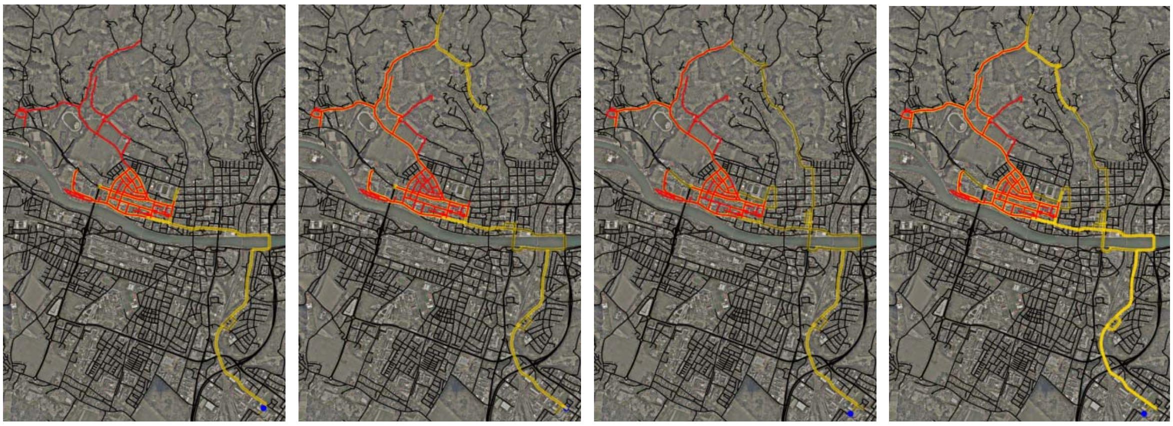

Figure 3: The analyzed plan no.1 and the route track of the vehicle 784. The last image shows the complete operation which consists of three loops whose tracks are shown (in yellow) in the former three pictures.

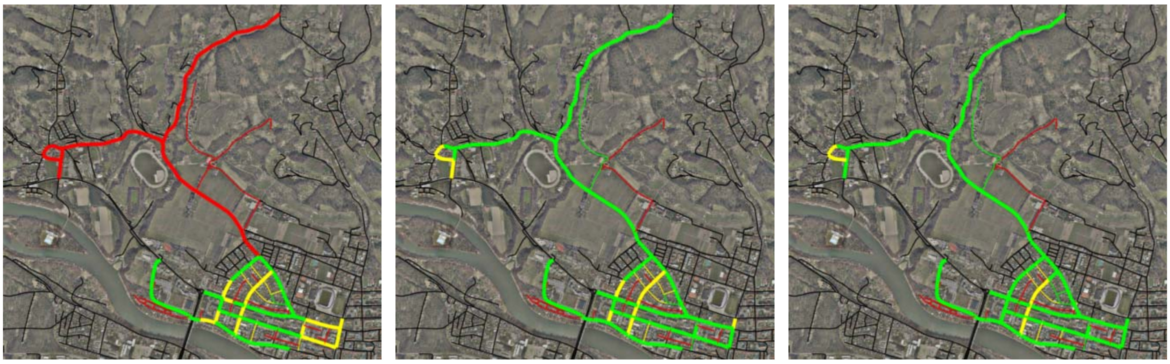

Figure 4: Coverage of the plan no.1 by vehicle 784. Thicker lines represent priority 1 sections (more important roads) while other lines represent prirority 2 sections. For each loop, red color denotes sections that are not processed at all, yellow represents partially processed sections, while green represents completeley processed sections. Three pictures represent cumulative situation after traversal of each of the three loops.

Figure 5: Coverage of road sections in the plan. Blue color represent priority 1 sections, while green sections represent priority 2 sections. Thin yellow lines represent sections of both priorities that are not processed at all. The thickness of the line represents the number of traversals after a given loop.

ISBN: 978-988-19253-1-2 (revised on 17 September 2013) WCECS 2013
ISSN: 2078-0958 (Print); ISSN: 2078-0966 (Online)

Table 1: The indicators of the action of the vehicle 784 on the plan no.1.

Vehicle ID	Plan	No. of loop	Beg. time	End time	Duration	Km plan	Km eff. plan	Km out. plan	Total len (km)	Eff. % cover	Len.% cover	Km cum. plan	Km cum. eff. plan	Km cum. total	Cum. % cover	Ef. cum % cover	Cum.% total
784	no.1	1	07.02. (22:11)	07.02. (23:34)	1:23:05	15,4	12,9	12,1	27,6	38,1%	45,5%	15,4	12,9	27,6	45,5%	38,1%	81,3%
784	no.1	2	08.02. (00:34)	08.02. (02:13)	1:39:12	23,2	19,3	14,8	38,0	56,8%	68,3%	38,6	24,0	65,6	113,8%	70,8%	193,3%
784	no.1	3	08.02. (02:45)	08.02. (03:50)	1:04:26	14,1	14,0	14,3	28,3	41,3%	41,5%	52,7	25,7	**94,0**	155,4%	**75,7%**	276,8%

Table 2: Indicators for the optimized routes for loops for the case under analysis.

Vehicle ID	Plan	No. of loop	Beg. time	End time	Duration	Km plan	Km eff. plan	Km out. plan	Total len. (km)	Eff. % cover	Len.% cover	Km cum. plan	Km cum. eff. plan	Km cum. total	Cum. % cover	Ef. cum % cover	Cum. % total
784	no.1	1	07.02. (08:00)	07.02. (09:34)	1:34:02	12,9	12,2	10,0	22,9	36,1%	37,9%	12,9	12,2	22,9	37,9%	36,1%	67,3%
784	no.1	2	07.02. (09:29)	07.02. (11:03)	1:34:24	13,3	11,9	10,1	23,4	35,2%	39,2%	26,2	22,5	46,3	77,2%	66,3%	136,3%
784	no.1	3	07.02. (10:58)	07.02. (12:41)	1:43:28	17,4	16,5	9,2	26,5	48,7%	51,1%	43,6	33,9	**72,8**	128,3%	**100,0%**	214,4%

Table 3: Optimization of plowing of the sections that have been actually plowed in the analysed case.

Vehicle ID	Plan	No. of loop	Beg. time	End time	Duration	Km plan	Km eff. plan	Km out. plan	Total len. (km)	Eff. % cover	Len.% cover	Km cum. plan	Km cum. eff. plan	Km cum. total	Cum. % cover	Ef. cum % cover	Cum. % total
784	no.1	1	07.02. (08:00)	07.02. (09:19)	1:19:06	10,5	9,5	9,8	20,3	38,4%	42,5%	10,5	9,5	20,3	42,5%	38,4%	82,3%
784	no.1	2	07.02. (09:14)	07.02. (10:53)	1:39:00	13,6	13,2	9,8	23,4	53,3%	54,9%	24,0	21,0	43,7	97,4%	85,3%	177,1%
784	no.1	3	07.02. (10:48)	07.02. (11:41)	0:53:26	7,4	6,9	9,2	16,6	27,8%	29,8%	31,4	24,7	**60,3**	127,2%	**100,0%**	244,2%

REFERENCES

[1] Toth, P., Vigo, D. (2002), “The vehicle routing problem”. SIAM, Philadelphia, Monograph on Discrete Mathematics and Applications, Philadelphia.

Modifed on 17 September 2013 for adding the second author.