DECISION SUPPORT SYSTEM IN CITY LOGISTICS

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ABSTRACT

Finding efficient and cost acceptable solution for supporting processes in city-logistics leads to multi-user multi-layer hybrid simulation systems incorporating latest technology achievements: from sophisticated computer and database systems thru latest large data set computing metaheuristic algorithms to Global Positioning Systems and other status update systems (exceptional traffic, hour/weekday traffic levels). In this paper example approach to design of Decision Support System (DSS) in city-logistic is presented. This includes proposition of multi-layer simulation system that incorporates existing hardware and software solutions (Data Center technology, TransCAD as pre and post processing GIS) and new metaheuristic solution algorithms (with experimental verification) and system topology design which make it more suitable for needs and economic capability of potential users. Although this paper concerns preliminary approach to creation of such system - currently extensive work is done to fully implement ideas presented and successfully verified on benchmarking sets.

INTRODUCTION

Urban freight transport is an extremely important activity in the context of urban life. Efficient transport is an important element of the urban economy, both in terms of the income it generates and the employment levels it supports. However, freight transport is responsible for traffic and environmental impacts in urban areas. The research has attempted to gain tools for simulating and handling the problems experienced by goods and service vehicles in urban areas:

- Traffic flow/congestion problems
- Parking and loading/unloading problems
- Customer/receiver-related problems

The enormous computing power available on the desktop, at nearly the price of electricity, enables a graphic, interactive, GIS-based approach to transportation decision support systems that can be accessible to almost every organization. This paper concerns the usage of advanced technologies that enable development of logistics decisions supporting software, proposes new optimization methods that have not yet been deployed in practice and shows achievements of metaheuristics algorithms for solving example problem: the Capacitated Vehicle Routing Problem (CVRP).

PROBLEM IDENTIFICATION

Any decision support system designed for City-Logistics should incorporate tools/methods that can simulate and handle with typical problems concerning traffic flow/congestion:

- weekday traffic levels
- exceptional traffic incidents
- seasonal variation in traffic levels
- inadequate road infrastructure
- lack of traffic problems information
- vehicle access time restrictions
- vehicle weight (and other) restrictions
- permanent road closures
- road design/layout

This leads to very expensive and overloaded database systems (with frequent and various updates) neither accessible nor maintainable to many organizations. Even thought data acquisition for such system seems to be possible nowadays it reaches economical barrier and can be implemented only in multi-user shared computer architecture based on third party Data Center technology as described in next chapter.

The only acceptable solution for this problem is creation of integrated computer system in one of two proposed architecture configurations: centralized or semi-distributed. First one gives economy savings while second gives better flexibility to potential user. Both assume usage of TransCAD from Caliper Corporation as core solution and visualization application with add-ins expanding its functionality and providing task-oriented user-friendly interface along with Mainframe Computers in Data Center as outsourcing solution. This approach gives great functionality and efficiency at reasonable price and guarantee professional maintenance and security of stored data. Participation of many companies in that project gives additional benefits – decision support system can easily obtain and use information about traffic generated by other participating companies. Of course this leads to another

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problem with privacy of information – any participant is interested in usage of such information but no one is interested in giving information about his activity, clients, fleet status etc. System proposed in this paper gives complex solution to this problem through access control in communication module and professional solution provided by Data Center.
The application of transportation models and solutions has always been a computationally intensive process. System proposed in this paper requires application of new methods of optimization for many transportations problems such as Vehicle Routing Problem, which is a complex combinatorial problem (and the most representative one). Due to its NP-hardness it is almost impossible to find the optimal solution for big instances of the VRP even thought mainframe computer power is used. That is why many heuristic algorithms have been proposed and used for solving the problem.
This paper relates to the usage of metaheuristics algorithms for solving the Capacitated Vehicle Routing Problem (CVRP) as an example solution that should improve computational efficiency of proposed multi-user decision support system.

SYSTEM CHARACTERISTICS

System is designed as a multi-level scalable computer system based on Data Center technology and TransCAD application as core solution and visualization engine implemented in one of two possible topologies:

- Centralized – where participants can use terminal-like technology, which offers full functionality of the system but limits possibility to modify or match specific requirements of participants while offers lowest possible operating cost.
- Semi-distributed – giving great flexibility due to possibility of implementing completely new modeling procedures and joining additional data not available in central database while still having full functionality of the system but with higher operating cost (installation and maintenance of additional database systems on client computers)

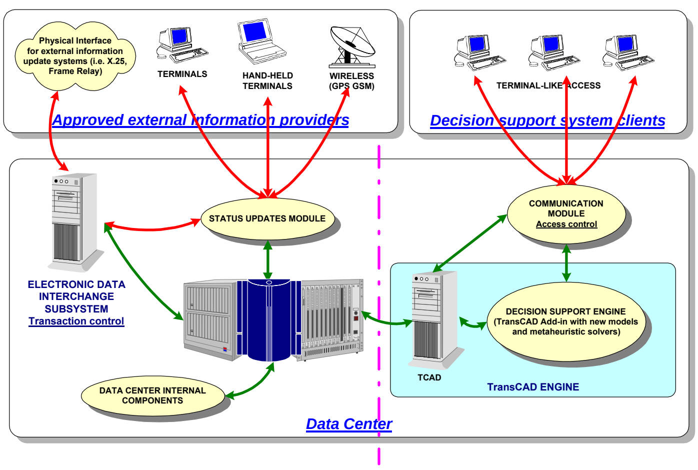

Fig. 1 Modular architecture of Centralized System

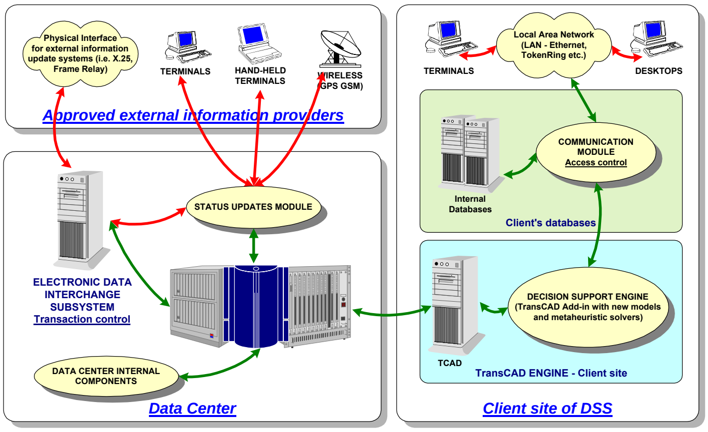

Fig. 2 Modular architecture of Semi-Distributed System

As shown on figures 1 and 2 in both solutions some elements are common so obvious that are not even detailed in this paper and only few are different and solution-dependent.
The most important element of the system is solution and visualization engine TransCAD from Caliper Corporation. This Geographic Information System has been chosen due to “natural gift” for transportation application. It can be replaced by any other GIS system offering similar functionality. TransCAD was designed as an open platform that facilitates the addition of user-written and third party extensions. The Geographic Information System Developer’s Kit (GISDK™) for TransCAD provides the tools for creating add-ins to TransCAD, macros to automate repetitive tasks, and the ability to implement custom model interfaces. Add-ins can implement completely new modeling procedures that can access TransCAD data or subroutines and thru the TransCAD functionality can access almost any database system. In this way, TransCAD is designed to avoid the requirement of massive code-writing for new analysis methods, and provides a cost-effective means of implementing new models.

The companies that have participated in the discussion held during the research have had the opportunity to express what actions they might want to be implemented in order to make the supply of goods and services easier to perform. As the result of this discussion Decision Support System architecture was designed (shown on fig.1 and fig 2) as the solution that fully satisfies potential participants of this project.
As proposed both solutions may coexist in single integrated multi-user multi-architecture system offering both (but exclusively) economic and flexible access to Decision Support System module and information stored and maintained in Data Center.
As another result of discussion a need for flexible user-friendly and task-oriented user interface has been denoted. Decision Support System should simplify and minimize user interaction with system when frequent and schematic functions are executed. In many cases user interaction can be minimized when information about past activity would be analyzed and reused – but

this leads to an expert systems not considered in this paper. On the other hand modern applications offer great flexibility at the cost of clarity or simplicity. Due to proposed architecture of DSS this inconvenience along with language/localization problem is solved – DSS is masking underlying solution and visualization system offering convenient user-friendly and task-oriented interface (see figure 3)

Not only the computer power and storage capacity is crucial when deciding which offer to accept – one of the most important is client access to this resources i.e. offered connection capability.

Talex S.A. Data Center WAN has star topology based on Frame Relay Polpak-T. Central point (Poznań) is connected via PVC links to its divisions in Warsaw and Wrocław. Every division has additional PVC link to

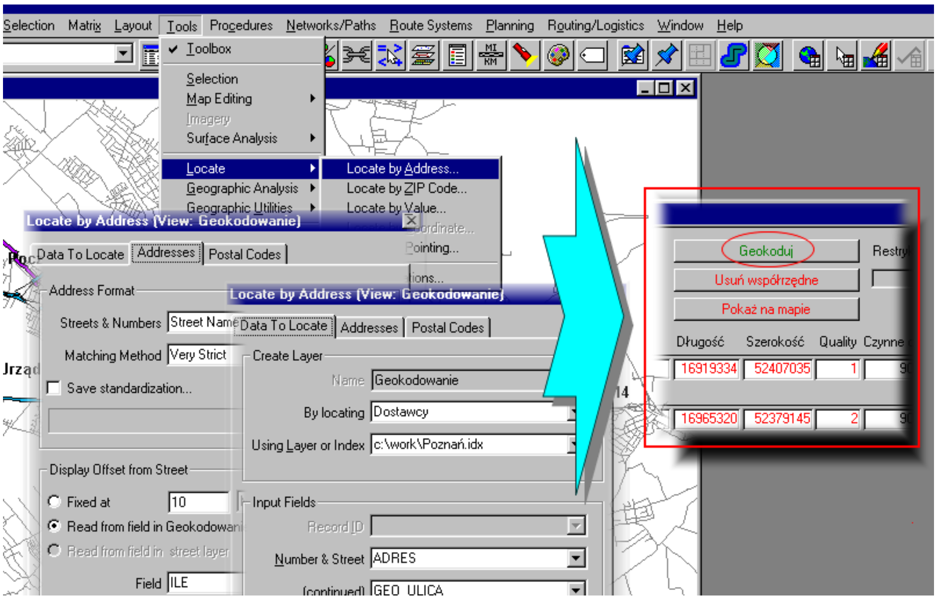

Fig. 3 DSS Masking Feature resulting with Localized and Optimized Interface

This approach creates real multi-level system where any underlying element can be replaced by any other solution providing compatible inter-level communication capability (i.e. when user interface calls sub layer for geocoding new localization it waits for execution status and after success assumes that all required data is written/updated in proper databases – existence of TransCAD in this example is not required nor checked, operation can be done by any other GIS application - MapInfo Professional for example)

DATA CENTER

As previously mentioned implementation of proposed system for many reasons is possible and cost effective only by means of outsourcing specialized companies offering Data Center technology. In our region one of the most well-known companies offering such solutions is TALEX SA

Their Data Center as certified by IBM fulfills rigorous requirements concerning:

- Localization,
- Servers room construction,
- Operational continuity,
- Telecommunication infrastructure,
- Professional client care, etc.

and thus seems to be the best solution for proposed intensive, heavily loaded computer database system

Internet (TPNet). SDH link of 34 Mb/s bandwidth allows 17 clients connections of 2 Mb/s each.

Although proposed system is designed for city logistics, possibility of wide network access can be helpful or required when decision centers are localized in other cities (in Warsaw as capital for example).

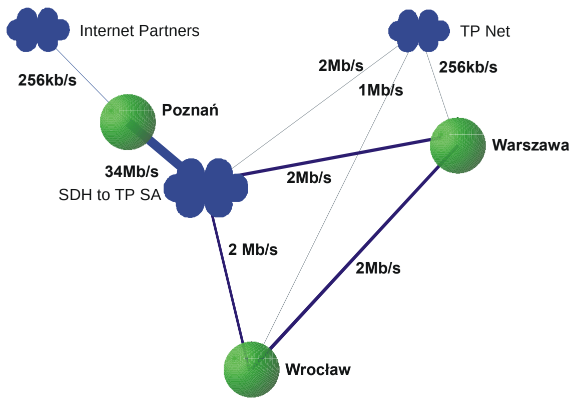

Fig. 4 Talex S.A. Data Center WAN

MULTIPLE OBJECTIVE METAHEURISTICS IN VEHICLE ROUTING PROBLEM

Decision Support System as described in this paper requires new approach to standard modeling procedures. This section describes one of the most representative:

multiple objective metaheuristics in vehicle routing problem. (designed and verified on simulation data as add-in expanding functionality of TransCAD solver)
In many real-world problems it is necessary to take into account many different and often conflicting objectives. In such problems there is no single optimal solution, but a set of many alternative solutions. At present multiple objective metaheuristics are a very active field of research.
In this chapter author's achievements in this field of research are summarized (for details see [1]).
In our research an extended Capacitated Vehicle Routing Problem (CVRP) has been studied. This extension involves multiple objective optimization. Three independent objectives have been selected arbitrary: minimization of total traveling distance, traveling time and number of vehicles.

Our multiple objective metaheuristics for CVRP have been based on Multiple Objective MetaHeuristic Library in C++ (MOMHLib++). MOMHLib++ is a library of C++ classes that implements a number of multiple objective metaheuristics. It has been developed by Jaszkiewicz (2001). In this library main multiple objectives metaheuristics are implemented in a consistent way, which allows easy adaptation of the methods to a given problem.
As our main research interest lies in evolutionary computations, genetic algorithms have been selected from the MOMHLib++. These are (with working abbreviations used in the further part of this paper):
1. Strenght Pareto Evolutionary Approach (**SPEA**),
2. Nondominated Sorting Genetic Algorithm (**NSGA**),
3. Nondominated Sorting Genetic Algorithm II **(NSGA II)**,
4. Controlled Nondominated Sorting Genetic Algorithm II (**NSGA II C**).

Also hybrid genetic methods have been studied, where global optimization is hybridized with local optimization (local search method). These algorithms are:
1. Multiple Objective Genetic Local Search by Jaszkiewicz (**MOGLS**),
2. Multiple Objective Genetic Local Search by Ishibushi and Murata (**IMMOGLS**),
3. Pareto Memetic Algorithm (**PMA**).

For the comparative purposes Multiple Objective Multiple Start Local Search (**MOMSLS**) method has been analyzed.

During calculations two alternative mutation operation have been used: node exchange (NX) and arc exchange (AX). These two operations are adopted from the Traveling Salesperson Problem (TSP). In case of node exchange two points in the solution sequence are exchanged. In arc exchange operation the sequence between two points (including the second of the two selected points) is inverted. Each change in arcs is connected with changes in time and distances traveled by vehicles.
Another operation is neighborhood search operation, which is necessary in local search optimization methods. For this purpose node exchange and arc exchange operators were used. But while in case of mutation the pairs of points are generated with randomness, in local search (where the neighborhood is searched in a systematical way) for each sensible pair the operation is performed.

Experiments have been conducted in two phases. In first phase the single objective optimization has been carried out (minimization of the total distance). It is due to the fact that there are no benchmarks for the multiple objective CVRP. The single objective optimization was conducted to prove (with success) that:
1. Our genetic algorithm operators and local search method operators are well suited to the CVRP
2. Our software (which implements the CVRP and the operators) effectively works with MOMHLib++

In the second phase experiments on the multiple objective CVRP have been carried out.
As a benchmark for the single objective CVRP optimization a number of well-known problem instances have been used. It includes instances form Augerat Set A (A-n44-k7, A-n54-k7, A-n80-k10), Augerat Set B (B-n31-k5, B-n41-k6, B-n57-k7, B-n63-k10, B-n78-k10) and Christofides and Eilon (E-n13-k4, E-n22-k4, E-n33-k4, E-n51-k5, E-n76-k10, E-n76-k14, E-n76-k7, E-n76-k8). Only few of those are presented in this paper.
For each method and for each instance two kinds of optimizations have been carried out. In the first one AX operator has been used for mutation and local search, while in the other NX operator has been used.
In case of genetic algorithms there is no significant difference in the results, so AX and NX operator are equally good for mutation. This has not come true in case of hybrid genetic algorithms and local search method, where AX and NX operators have been used for searching the neighborhood. In this case AX operator performs much better than NX. It is probably because less disturbances in solutions appear when AX is used, so this operator gives more chance to precisely search the current solution neighborhood.
But more meaningful are differences in performance between algorithms. Best results have been obtained for the hybrid genetic algorithms (especially for MOGLS and PMA). Local search (MOMSLS) has performed well. The worst performance has been reached by the genetic algorithms (especially by SPEA and NSGA, see table 2). All four genetic algorithms use Pareto-ranking for assessing fitness for each chromosome.

The poor performance of these genetic methods is due to the fact that Pareto ranking is not informative enough to carry out the optimization well.

Table 1 Example results of the single objective CVRP optimization (underlined – the best solution given in the repository of these benchmarks, **bold** - values equal to the reference values, *italics* – better than the reference ones)

Test	Op	SPEA	NSGA	NSGA II	NSGA II C	MOGLS	IMMOGLS	PMA	MOMSLS
A-n32-k5	AX	1364	1399	855	863	796	796	796	820
(784)	NX	1348	1429	862	882	796	803	801	846
A-n44-k7	AX	1631	1778	1089	995	**937**	942	942	961
(937)	NX	1802	1812	1042	1009	**937**	948	945	996
B-n31-k5	AX	791	854	684	677	**672**	**672**	**672**	678
(672)	NX	840	849	713	685	677	677	677	682
B-n57-k7	AX	2289	2565	1342	1489	*1145*	*1147*	*1148*	1177
(1153)	NX	2462	2602	1185	1345	**1153**	1155	*1147*	1221
B-n78-k10	AX	2979	3195	1591	1442	*1229*	*1242*	*1224*	1302
(1266)	NX	3132	3234	1494	1435	1279	1303	*1257*	1377

Table 2 Computation times (in seconds) of the single objective CVRP optimization

Test	Op	SPEA	NSGA	NSGA II	NSGA II C	MOGLS	IMMOGLS	PMA	MOMSLS
A-n32-k5	AX	1	6	7	7	14	18	9	2
	NX	1	6	7	8	15	21	10	3
A-n44-k7	AX	1	6	8	8	43	58	41	7
	NX	1	7	7	8	44	73	38	7
B-n31-k5	AX	1	6	7	7	10	12	8	1
	NX	1	6	7	8	12	18	12	1
B-n57-k7	AX	2	7	7	8	147	179	119	23
	NX	1	7	8	8	180	196	126	23
B-n78-k10	AX	2	8	8	9	427	634	370	76
	NX	2	7	9	8	569	765	451	91

Table 3 Computation times (in seconds) of the Multiple Objective CVRP Optimization

Test	S	SPEA	NSGA	NSGA II	NSGA II C	MOGLS	IMMOGLS	PMA	MOMSLS
A-n32-k5	C	2	6	8	8	18	24	14	1
	L					14	24	12	2
A-n44-k7	C	1	7	8	8	57	78	53	6
	L					50	82	46	7
B-n31-k5	C	1	7	7	8	15	21	13	2
	L					13	21	12	2
B-n57-k7	C	2	7	8	9	93	136	90	10
	L					212	297	199	24
B-n78-k10	C	2	7	9	9	611	988	606	73
	L					579	987	582	80

The experiments have shown that methods based on Pareto ranking perform much poorer than those based on scalarizing functions. Computation times are presented in table 2. Algorithms using local search method works much slower, because this method is extremely time consuming. Since parameters of all methods were constant, they do not depend on n, where n is the size of the problem, what determines the size of solution representation. Time results only depend on n.

In case of the genetic algorithms computation times are rather constant (they minimally increase with increasing n). This is due to the fact O(n) is the complexity of operations on chromosome such as reproduction or calculation of objective values. But these operations are less time consuming in attitude to the rest, thus so minimal impact of n on computation times.

In case of the hybrid genetic algorithms and the multiple start local search algorithm things change. Local search is time consuming to such a large extend, that computation times are very high. The size of neighborhood in the local search is O(n2) for both AX and NX neighborhood operators. Exactly neighborhood sizes are n(n-3)/2 and n(n-1)/2 respectively. A single search of the neighborhood is O(n3) because of additional complexity related with operations on chromosomes. But the results show that the total complexity is O(n4). This fact can be explained in the following way. The number of all possible solutions (assuming our solution representation) is n!, but during a single iteration of local search less then n2/2 are analyzed. Thus when n increases it takes more iteration to find the local optimum, because the neighborhood becomes smaller in relation to the whole solution space.

The second phase experiments have been carried out only for AX operator (because of better performance). On the other hand computations for methods incorporating local search have been conducted for two variants of scalarizing functions (linear [L] and Chebyshev [C] functions). Instead of presenting the results in table appropriate diagrams illustrate the results.

Next three diagrams (figures 5, 6 and 7) present the results obtained for A-n32-k5 instance. All solutions in the set have the same value on the third objective – in all of them 4 vehicles are required. For greater clarity all points are connected and create an approximation of the Pareto front.

In the multiple objective optimization again the hybrid genetic algorithms perform the best (especially MOGLS and PMA), while the genetic algorithms give the poorest results. Another conclusion after detailed analysis is that linear scalarizing function (L) is better than Chebyshev (C) one.

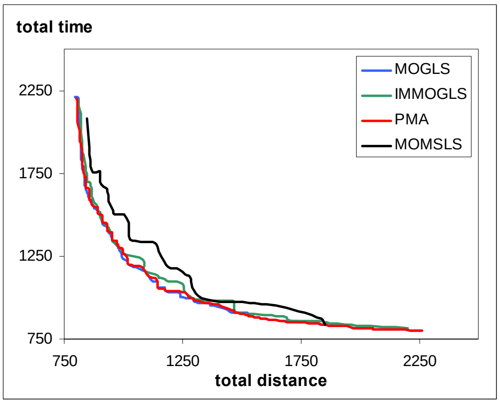

Fig. 5 Results for A-n32-k5 using linear scalarizing function (Hybrid Genetic Algorithms)

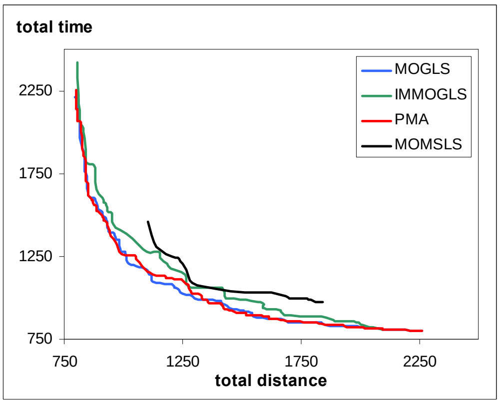

Fig. 6 Results for A-n32-k5 using Chebyshev scalarizing function (Hybrid Genetic Algorithms)

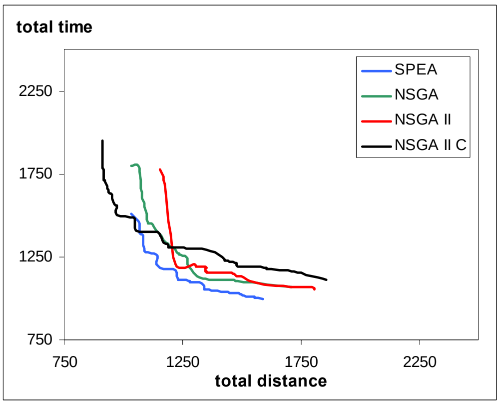

Fig. 7 Results for A-n32-k5 (Genetic Algorithms)

The second phase experiments also proved that PMA and MOGLS give best results, IMMOGL is quite worse while the genetic algorithms using Pareto-ranking perform worst.

A second conclusion is that computation times in case of the multiple objective CVRP are longer. It is due to the fact that in the single objective version approximation of the nondominated set consists only of one solution, while it the multiple objective version – lots of solutions create the approximation.

Results achieved for test problems authorize us to evolve algorithms into system proposed in this paper and make experiments on real life examples. Currently extensive work is done towards integration of presented algorithms with designed DSS for city logistics and TransCAD to gain access to real life data (with proposed Data Center technology), visualization engine and localized user-friendly interface.

CONCLUSIONS

The key aim of the exploratory research was to provide practical tools for use by public sector organizations, freight transport operators and industrial and commercial firms who are working towards establishing a more sustainable urban environment.

In this paper the multiple objective approach to the Vehicle Routing Problem has been presented. Multiple objective metaheuristics are quite a new, but fast evolving research domain. There have been many successful attempts to apply these metaheuristic methods to such problems as the Traveling Salesperson Problem or the 0/1 Knapsack Problem. In case of the VRP an algorithm for bi-objective optimization was proposed and then applied it to the bi-objective VRP. The approach presented in this paper allows using of more than only two objectives and with other elements offers efficient and cost acceptable solution for supporting processes in city logistics

Although this paper concerns preliminary approach to creation of presented system – in fact currently extensive work is done to fully implement ideas presented and successfully verify on benchmarking sets.

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