Optimization of logistic processes with computational intelligence

Logistic (transportation) systems may be viewed as sets of complex human, social, economic, and political interactions, where for handling the obvious uncertainty traditionally probability theory has been used by present. On the basis of evidence presented by recent research results possibility theory offers a more flexible way of handling the uncertain situations that often arise in logistic (transportation) analysis. The two classes of uncertainty concerning logistics are vagueness, which is associated with the lack of clarity of the definition, such as the loss caused by a delivery delay, and ambiguity, which is associated with the lack of clarity in information, e.g., the predicted cost elements are often ambiguous.

The key factors ih logistic problems (similarly to other engineering and management applications) are resource intensity (time, space and physical vehicles, etc.) and the "goodness" (optimality efficiency, etc.) of the solutions applied. The satisfaction of customers has - in general terms - nonlinear characteristics, moreover, when time is included in the optimization, subjective elements have a significant effect on evaluation, so prospect theory must be involved in the analysis.

The typical logistic optimization problems are very often discrete mathematical problems, which represent NP-hard tasks, thus the efficiency of the applied heuristics, (e.g., evolutionary algorithms) is a critical issue of the problem. Maybe the most important stream within the project focused on the optimal and quasi optimal (but very efficient) solution of this very wide class of problems. In this respect we have experimented with various meta-heuristics and have achieved strikingly good results.

Considering the special features of logistic processes, it seems to be necessary to develop dedicated optimising principles, strategies, techniques and tools in order to explore methods that provide appropriate means for practical use.

1.

The main focus of the research was to identify the principal difference between general optimization theory and logistic optimization, such as the nature and uncertainty of input data, the nonlinear behavior of the objective functions, and also the side-effects of the decision-makers' subjective assessment, the problems that have to be solved when NP-hard problems describe real life tasks.

In the first phase of the research the application problem class was connected with infrastructural networks. The localization of failures in infocommunication and logistical networks is a typical

example for the above. Here we proposed a new evolutionary algorithm based approach. In the benchmark applications our new methods lead always to the absolute optimum. Resource allocation in networks or (discretised) closed topological areas was another one of them. Applying the evolutionary and evolutionary memetic algorithms that our group had developed in the frame of a previous project (OTKA K75711) essentially new results could be achieved in this area. The applicability of the approaches proposed here was successfully demonstrated on two different logistics engineering applications: energetic networks maintenance and construction site depository optimization. Related to these results the problem of cognitive biases in the (quasi-) optimization process, further the related correction mechanisms were also examined.

We have achieved results in the Permutation Flow Shop Problem occurring in production logistics by applying the above optimization approaches. We continued our previous research (in the frame of the previous project) in the area of solving NP-hard discrete optimization problems by testing various evolutionary meta-heuristics. In the last project year eventually we achieved strikingly good results. All the meta-heuristics were based on the bacterial evolutionary algorithm. As in the previous project demonstrated it on a wide range of areas, bacterial is unambiguously superior compared to all variations of the widely genetic algorithms and better and comparable to particle swarm optimization. The key factor is however to find a suitable local search method. The challenge here is to achieve fast convergence in the neighborhood of optimum and the same time ensures an acceptable over all runtime.

The first simulation runs on various size reference problems showed very slow convergence for small size problems and still low convergence for medium size problems compared to the Lin-Kernighan and the CONCORDE algorithms while for large size (over 1000 nodes) produced comparable runtimes, even in some cases, faster convergence, while the optimum was identical.

As an interesting side effect of this experimenting we started to work on a new definition of "well usable" algorithm in the sense that with guaranteed convergence or "almost convergence" the runtime is predictable, namely, our algorithm has a stable tendency in the increase of runtime in terms of the node number while the reference algorithms are very unpredictable. Continuing research in this direction could be the topic of a next project.

In the next we have experimented with various local search approaches, reducing the relatively high runtime of the 2-opt and 3-opt discrete local search methods. The resulting best local search solution produced almost identical optima with the reference algorithms and still more than one order of magnitude gains in the runtime compared to the best reference solutions!

2.

Another new research direction dealt with a key field of logistics: Waste Management Systems. The transportation, processing and disposal of waste is nowadays in the very center of interest. While the engineering and transportation parts of this problem play important roles, other aspects, such as the management, legal and institutional, social and environmental aspects are just as important. In order to build up reliable and relevant models of the problem, where besides short time and long time prediction of the evolution of each factor we focused on investigating the mutual influences among these components, and particularly on the sustainability of the whole.

The new model is based on Fuzzy Cognitive Maps, a type of non-layered artificial neural network. The crucial problem is the proper choice of parameter values which was done by evolutionary (bacterial) algorithm. In order to be able to properly model the waste management system we needed reliable data. As no explicit data for the period before 1990 were available, a special workshop was organized for identifying the importances and effects of the main components of waste management systems from textual documents of the period, using the frequency of critical words and expressions occurring in them. From this analysis we obtained data time series and on these new data it was possible to apply the new FCM model. Using the experts' estimations and then the constructed time series data we produced converging thus sustainable systems in every realistic case.

Based on the expert workshop a totally new detailed model of waste management systems was also created consisting of 33 sub-concepts partly having internal connections among themselves. The simulation by the new fuzzy-neural-evolutionary model led to entirely novel recognitions concerning the components of this complex logistic "system of systems" including some secondary reductions of the components. While the engineering and transportation parts of this problem play important roles, other aspects, such as the management, legal and institutional, social and environmental aspects are just as important. In order to build up reliable and relevant models of the problem, where besides short time and long time prediction of the evolution of each factor we focused on investigating the mutual influences among these components, and sub-components, devised from them and particularly on the sustainability of the whole.

Based on the reconstructed time series data we applied a new concept reduction algorithm and thus obtained a family of reduced management models with concept numbers between 8 and 30. By comparing these results and respective sustainable states with the reality we proposed several new models for waste management systems. (The new models can not be nested into the six concepts model in the literature!) As a side product of the research the new reduction algorithm has been introduced in the FCM research community.

We extended our investigations into modeling other management systems, especially those of various transport, service and productions companies. We started collaboration with Kaunas University of Technology and received large amounts of data on the management systems of Lithuanian transport companies. We succeeded in comparing the sustainable states of typical Hungarian and Lithuanian company management systems.

This rather application oriented research stream lead to purely methodological research and strongly international collaboration. The problem of extending and reducing FCM models lead to the proposal of several new algorithms and techniques, the most important among them being a concept reduction algorithm based on fuzzy tolerance relations and fuzzy clustering. This research was embedded in the main stream IEEE FCM research environment and we started collaborate with German, Greek and Turkish researchers (resulting in an accepted IF paper and a further submission). Another aspect of the same research lead to Finnish and French collaboration – still ongoing. At the time of preparing this report the acceptance letter of a high impact factor journal arrived for our submitted paper on these results.

One successful PhD defense was completed based on these results.

3.

The third major sub-project of the research may be identified by the application of a new modeling tool proposed earlier by our team. This tool is suitable to describe complex phenomena with multiple descriptors interconnected or arranged in sub-groups in a hierarchical manner. The tool includes fuzziness in the concrete descriptors, thus allows partial satisfaction of properties and conditions, a certain amount of undeterministic behavior and weighness in the environmental conditions. Even basic fuzzy signatures allow a very wide application field connected with logistics, so our research also split into several sub-sub projects.

An important topic in logistics is the application of automatic guided vehicles for transportation of goods, especially within closed environments such as factories and warehouses. We did algorithmic and simulation based research on applying intelligent mobile robots for modeling AGV's. We proposed a new mathematical tool for the intelligent control of such robots: fuzzy situational maps (FSM) – fuzzy signatures combined with a spatial structure. This new approach can be applied for modeling 2D or 3D warehouses in general. The 3D FSM model was successfully applied to modeling a real company's warehouse system, including the optimization of the inbound and outbound product flow.

Fuzzy signatures can be efficiently used in the logistics of building construction, including the optimal transportation and storage of construction materials, the evaluation and the optimization of the renovation of residential buildings. For this purpose Fuzzy Signatures, the new model of Fuzzy Signature State Machines (a combination of finite state machines and hierarchically structured multi-component fuzzy descriptors); traditional mathematics based sensitivity analysis (the determination of the upper bound of the error in terms of the error caused by the subjectivity in the expert surveys); and evolutionary algorithms were deployed. Fuzzy signature machines are a still partly unexplored new field and we expect to achieve further interesting results in the future, especially by combining FSig machines with evolutionary and memetic optimization and search algorithms in order to find best or relatively best solutions for optimizing the logistics processes in the procedure of the maintenance and renovation of built constructions. We very much hope to be able to continue this research in the future (maybe in the frame of a new fundamental basic project, and in a GINOP project, the proposal submitted recently). At this point this stream of the project would merge with the first stream, as the optimization of complex FSig machines in general case falls in the category of NP-hard problems, and thus needs similar optimization meta-heuristics.

Fuzzy signatures as powerful tools per se are important to be investigate as complex constructs with uncertain descriptors. We performed the analysis of the behavior of fuzzy signature descriptors, especially from the point of view of calculating the mathematical sensitivity of the resulting membership degrees based on calculations starting from linguistic labels assigned by experts. Although this analysis was mainly motivated by the need of being able to determine the validity of consequent and in the last year we were able to present some rather general mathematical models which may be useful in the evaluation as various model fuzzy aggregation constructs.

Another very recent result in connection with fuzzy signatures nested in the modeling sister research project deals with the algebraic structure of fuzzy sets with FSig memberships.

This stream resulted in two successful PhD defenses and an innovative MSc Thesis.

4.

A very special field within logistics is the automatic identification of symbols and characters identifying vehicles, containers and other objects. We have done successful research towards developing a new family of algorithms (FUBAR) that has produced better recognition rates for hand written capital letters than any method known from the literature or from any commercial product.

The mathematical approaches used in the above specifically logistics related research threads maybe considered as a single toolbox, the toolbox of Computational Intelligence. The approaches applied are

all connected to fuzzy systems, especially fuzzy signatures, situational maps (3D signatures) and grids, fuzzy cognitive maps and fuzzy rule based models, further evolutionary optimization algorithms (bacterial, particle swarm, etc.) and hybrid local search (discrete and continuous) techniques. The applied techniques connect this stream with streams one and three as well. We applied the combination of fuzzy models with evolutionary parameter optimization for character recognition with good results.

5.

A somewhat border line area of logistics is the optimization of communication and energetic networks. We attempted to optimize the quantity and quality of measurements necessary to predict the transmission properties of telecommunication networks. Further we proposed a completely new complex approach combining fuzzy rules and wavelet transform to predict the transmission properties of telecommunication networks. We expect that the very promising results thus obtained (better prediction, less expenses!) will be widely applicable to various logistics and recognition related engineering applications.

In the last project year the approach reach a stage where we may claim it is superior to all other results published in the literature. We drastically decreased actual measurement of the lines while pre-qualification results are dramatically improved in comparison to any method known in the professional literature. The pre-qualification values produced by our method combining interpolative fuzzy rule bases and a certain type of wavelet transform allows much higher exact prediction and almost zero error in the direction of higher class pre-qualification compare to other methods and real parameters.

Further two PhD Thesis in connection with the above researches are in the submission procedure.

6.

In the frame of the project several minor results were achieved in addition to the above main research streams. They are briefly listed below.

We have researched large scale supply chain system modeling based on I/O data. We proposed the application of tensor product approximation and higher order singular value decomposition, the latter in data representation. New results have been achieved in applying Artificial Neural Networks for decision support in supply chains. Artificial Neural Networks were also applied successfully for the production control of small batch production. Other intelligent approaches were proposed for decision making in the flow control mechanism in the construction industry.

A further thread of our research focused on interaction of humans and machines (e.g. in logistics processes and technologies), where we proposed some new cognitive info-communication approaches.

Some initial results showed that applying a fuzzy system based approach in social recommender systems could improve the quality of such systems in comparison to the non-fuzzy approaches. Recommender systems might be an important component of logistics and marketing.

Summarizing this final report we may state that the four year research project was rather successful and we have achieved several interesting results that had good reactions in the international professional community. The number and quality of publications certainly supports disclaim, while several impact factor journal papers are yet in the submission phase.