APPLICATIONS OF INTELLIGENT SYSTEMS IN TRANSPORTATION LOGISTICS

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Unluckily, in the recent literature the number of papers on the application of intelligent systems, especially fuzzy sets, have been decreasing considerably. The potential for those applications, however, has not diminished at all. On the contrary, the more complex applications become and the more decision support systems rely on human knowledge and experience, the more relevant and attractive become intelligent techniques. For publications, however, very often the problem arises, that those applications are not suited for publication because they are too complex for any one paper. In this paper it will be attempted to describe important applications in traffic control, in container terminal management and in ground control of airports and give further indications on other possible applications.

1. Introduction

Transportation logistics is a rather heterogeneous area. It includes public transportation, traffic management (i.e., the control and guidance of streams of individual drivers), fleet management, in-house-logistics (Hubs, industrial companies, container-and other harbors, hospitals) and other more specific areas. Problems in the different areas of logistics differ to various degrees from each other. They have, however, a number of features in common: The standard (model)-problems in transportation logistics, such as routing, dispatching, assignment, normally require the solution of large combinatorial problems; they are very often very complex and not easily perceived by human beings; they include a lot of uncertainty and they differ from each other in the specific context, i.e., solutions to these problems have to satisfy various constraints, which are very often imposed by human requirements and, therefore, not crisp but fuzzy and rapidly changing. In addition many of these problems have to be solved almost online and, therefore, require very fast computations.

Computational Intelligence, i.e., Fuzzy Technology, Neural Nets and Evolutionary Computation, offers a number of features which, sometimes in combination with classical methods, are very well suited to solve problems of transportation logistics better than it has been possible in the past. These are in particular:

Uncertainty modeling: Here fuzzy technology offers various ways to model uncertainties which are not random but either linguistic in character. These can be modeled in a more adequate way than using, for instance, probability theory.

Relaxation: Often problems are not dichotomous in character. Many traditional mathematical methods, however, (such as linear programming, cluster methods etc.) base on dual logic and therefore can only be properly applied to models with dichotomous elements (such as clusters, constraint solution spaces etc.). Fuzzy technology has been used extensively to generalize optimization methods, so that they can be applied to non-dichotomous models, without loosing their computational power.

Compactification: Due to the limited capacity of the human short term memory and the way human beings perceive reality, it is often not possible to either store all relevant data or to present masses of data to a human observer in such a way, that he or she can perceive the information contained in these data. This very often leads to situations in which relevant information is "hidden" in these data without being available to the human observer. Fuzzy technology has been used to reduce the complexity of data to an acceptable degree, usually either via linguistic variables or via Fuzzy data analysis. In this respect also Neural Nets can be used, since they are particularly suited for pattern recognition, which is also a kind of complexity reduction.

Meaning preserving reasoning: Expert systems technology has already been used since four decades and has in many cased lead to disappointment. One of the reasons for this might be, that expert systems in their inference machines, if they are based on dual logic, perform symbol processing (they process truth values and not knowledge). Fuzzy set theory has been used to "expand" dual logic by "linking" the meanings to the statements and words in the rule. Then, of course, also the inference engine has to be able to process meanings rather than symbols. This way of modeling human reasoning is generally referred to as "approximate reasoning".

Optimization: Combinatorial optimization is known to be very demanding and often heuristics have to be used rather than exactly optimizing methods in order to determine good solutions to real problems in acceptable time. Here methods of Evolutionary Computation have proven to be very effective and flexible. They seem to be particularly suited when combinatorial problems have to be solved fast and dynamically, i.e. if problem structures change gradually and the search for a new solution can make use of good solutions which have been determined before. It has even been shown, that unsupervised Neural Nets can be used to determine solutions for the travelling salesman problem.

It is beyond the scope of this paper to describe all existing and potential applications of methods of Computational Intelligence to problems of transportation logistics. In the following it will rather be attempted to sketch major applications in the most important areas of logistic, to describe exemplarily some typical applications in more detail and to point to several potential applications of CI in logistics, which have not yet been tapped. Before considering the different areas it might be useful to define what is meant by "application": Application may mean the application of one theory to another. For instance, applying fuzzy set theory to linear programming yields fuzzy linear programming. It can also mean applying one theory to a model. For instance, applying fuzzy linear programming to an inventory model may also be called an application. Eventually application can mean the application of theories or models to real world problems. In the rest of this paper "application", if not stated otherwise, always has the last interpretation, i.e., real world applications.

2. Traffic Management

Four major fields of traffic management can be distinguished: 1. Traffic supervision, traffic condition forecasting and evaluation. 2. Modeling of individual driving behavior. 3. Choice of optimal routes. 4. Traffic control.

1. Traffic supervision: There are hardly any publications in this area, but some systems exist and work. They collect information about the traffic flow (particularly on expressways), merge this information with other data, evaluate the traffic condition and forecast traffic conditions in other parts of the traffic network [1]. On the basis of these forecasts either suggestion for route choices are broadcast to the traffic participants or the speed limits posted (in central Europe for instance every kilometer) are set such as to avoid traffic jams and accidents [4]. Fuzzy data analysis and neural nets are used for judging and evaluating traffic conditions. Fuzzy control is used to determine automatically the optimal maximum speeds posted [2]. Large potentials of applications in this area have not yet been tapped, presumably due to the shortage of finances of public institutions at the present time.

2. Modeling of individual Driving behavior: Some empirical research has been done on modeling individual driving behavior with fuzzy models. Results of this research entered as input into projects that tried to model traffic network models. No practical applications are, however, know so far.

3. Route Choice Behavior: Fuzzy approaches that have focused during the last three decades on this problem can be classified into cost minimizing and ranking approaches. They have not yet had any important impact on existing systems.

4. Traffic Control: This is certainly the most interesting and also most heterogeneous contribution that Computational Intelligence has made to traffic management [3]. One of the most often considered problem is that of intersection control. Applications are primarily based either on simulation or knowledge based fuzzy models, i.e., on fuzzy control models.

3. Fleet Management

Theoretically fleet management means assigning schedules to vehicles or drivers. Since a fleet consists of many elements (trucks, ships, etc), the locations that have to be served by these elements have to be distributed to the elements (these are called tours) and for each element a sequence has to be determined according to which the locations have to be visited. This is called a route. No matter whether a route- first-cluster-second or a cluster –first-route- second approach is used, the routing problem always constitutes a combinatorial problem. The best known model for this type of problem is the so-called "traveling salesman problem" (TSP), of which many variants exist and for which very many solution methods have been invented. One of these methods is genetic programming. It has even been shown, that unsupervised neural nets can be used to solve this problem. Which of these methods is the best depends very much on the context. Particularly time windows and other types of constraints imposed on the route influence very much the suitability of the respective methods. Traditionally it is assumed that in a TSP each location is only visited exactly once and that the mobile element arrives at the starting point at the end of its route. This, however, is not always true in practice. It has also been observed, that integer linear programming solutions (for instance for optimizing scheduling containers on containerships) turn out not to be feasible due to the fuzzy character of constraints. Fuzzy linear programming in this case has proven to be very helpful [5].

4. In-House-Logistics

The last two paragraphs considered logistic problems in a kind of macroscopic way. Logistic problems cause considerable costs inside of companies and other units also. If one considers the peace part production in a factory, for instance, then usually each department has its own means of transportation (craddle carriers, fork lift trucks etc.). These trucks are sent out to get material from other departments and also to bring finished goods to stores. Normally the transportation capacity is empty one way of the trip, resulting in a capacity utilization of around 50%. This is due to the fact, that the departments do not know of the transportation requirements of other departments. If the control of all means of transportation is centralized then two possible scenarios exist: Either the material flows are that steady (in direction and quantity) that fixed routes can be established on which transportation is carried out regularly. Or this is not possible; then the control center faces a very serious problem: By contrast to the traditional TSP structure mentioned in Section 2, now each location (department) can be a well and a sink at the same time. In addition demands for transportation occur irregularly and with different urgency and the scheduling cannot be done in advance but has to be executed on-line. Hence many assignment and scheduling problems have to be solved simultaneously and very fast. With modern hard-and software and using a combination of modified traditional Operations Research algorithms and heuristics this task can be solved [7]. It has turned out, however, that each application poses several specific demands due to physical conditions as well as context dependent demands by the users. These demands are generally not crisp but rather approximate. Here, however, a closed formulation in the form of a fuzzy algorithmic model can hardly be achieved. Therefore knowledge based modules were added to the crisp control system, which could accommodate necessary modifications of the results such that the additional constraints were satisfied. Since the rules were modeled as fuzzy relations containing linguistic variables, the inference engine had to be able to perform meaning preserving reasoning rather than only symbol processing.

Above it was referred to factories. The same basic structure – and the same complications – can also be found in airport ground operations, in big hubs in which parcels have to be reloaded, and even in hospitals. In the latter additional (very often fuzzy) constraints have to be taken into consideration, since not only costs but also the safety of the patients, legal constraints and other criteria become very important. Nevertheless in more than 10 of the largest German hospitals such intelligently controlled systems have been installed which work to every body's highest satisfaction.

In order to convey to the reader an impression of the complexity of such systems one example shall be described in some more detail [8]: The control of the transport operations of a newly built container harbor. Figure 1 shows schematically the basic layout of such a container terminal.

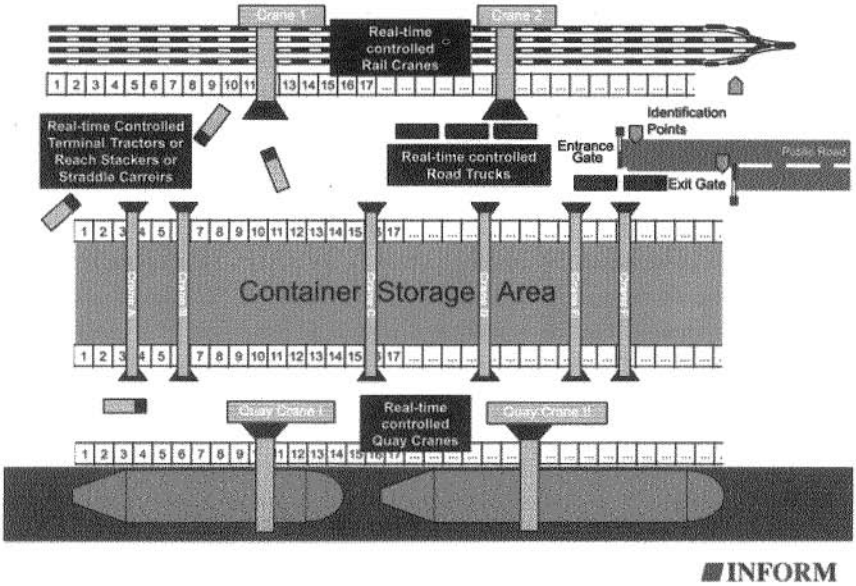

Figure 1. Layout of Container Terminal.

The *real parameters* are: On the landside there are 6 rails (train length up to 2000 feet), 4 RMG's (Rail Mounted Gantry Cranes), 200 chassis and 20 tractors. The storage area contains 22 blocks (each 10 lanes/37 bays/4-5 tiers) = 370 ground slots per block; 2 blocks for "Out of gauge containers", 1 block for empty containers. This amounts to 30 000 TEU's in total (where only 80-90% is used to improve shifting quality). The blocks are covered by 44 RMG's (1 pair per block).

The waterside has 4 landing stations for container ships (quay length 4000 feet), Ships are loaded and unloaded by 14 container bridges and the containers are carried between the container bridges and the blocks of the storage area by 60 AGV's (Automated Guided Vehicles) with a speed up to 15 mph.

Obviously, the cranes can well be controlled by fuzzy control, one of the earliest techniques of applied fuzzy set theory. There are other activities, however, that require even more powerful decision making tools. Before a container is loaded, for instance, from a container bridge onto an AGV it has to be determined to which slot in the storage area this container has to be transported. Goals for this decision are to minimize the number of shifting operations (of other containers), to maximize the utilization of the storage space, and to minimize distances from the departure to the delivery location. The slot to which the container is moved obviously determines the distance. Strictly speaking the distance, for instance, to the train when it is loaded on a train for further transportation also has to be considered. Hence, the suitability of a slot for a certain container depends on the attributes of the container, the type of the slot, and the types of the neighboring slots. Each of the attributes has between 3 and 10 possible values and those values are partly singletons and predominantly fuzzy in nature. Accordingly they are considered as linguistic variables. On one hand that has the advantage that the respective rules are transparent and can be judged by human experts. On the other hand the inference becomes very demanding and requires an efficient and structured inference engine. This particularly if the available time frame is considered and if one considers that their may be up to 10 000 potential slots in which a container can be put.

There are 14 container bridges with cycle times between 45 and 60 seconds, 4 rail cranes and 12 in gates for trucks. Hence 30 demands for an assignment decision can arrive during a time interval of 45 seconds. This means, that approximately 1 second is available for each decision. It would be very hard, if not impossible, to solve this type of problem with conventional types of algorithms. Approximate reasoning as well as genetic algorithms seem, however, to lead to acceptable solutions.

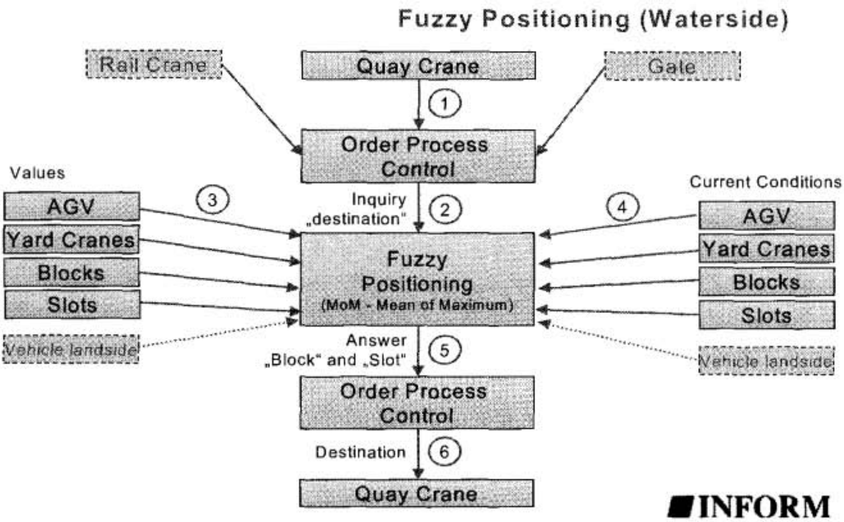

Figure 2. Container Movements.

5. Conclusions

Transportation logistics for material as well as for personal is an important area and it will increase in importance and complexity in the future. It is a heterogeneous field that stretches from traffic management via Supply Chain Management and fleet management to in-house-logistics.

It has been shown that methods of Computational Intelligence can contribute substantially to solving open problems or improve non-satisfactory solutions. By contrast to the beliefs in the 90's there will hardly be any "fuzzy systems" that solve problems, but fuzzy modules will be combined with classical dichotomous algorithms wherever that is appropriate. In this paper examples were described that reached from application of fuzzy clustering and neural networks in traffic management to approximate reasoning in in-house-logistics. It is hoped that those examples indicate the large potential for further scientific developments and for applications in this area.

References

1. Landenfield, M., Cremer, M.. Fuzzy Control Strategies for Oversaturated Urban Traffic Networks Using Queue Lengths and Origin Destination Information. *Proceedings of the '97 IST World Conference, Berlin* (1997).
2. Lin, C.-K., Chang G.-L. Development of a Fuzzy Expert System for Incident Detection and Classification. *In: Mathematical and Computer Modelling*, 27, Issue 9-11, 9-25 (1998).
3. Sasaki, T., Akiyama, Fuzzy On-Ramp Control Model on Urban Expressway and its Extension. *In: Transportation and Traffic Theory, Amsterdam*, 377-395 (1987).
4. Schretter, N., Hollatz, J.. A Fuzzy Logic Expert System for Determining the Required Waiting Period after Traffic Accidents. *EUFIT, Aachen. In: Proceedings'96*, pp. 2164 – 2170, (1996).
5. Zimmerman, H.-J, Fuzzy Programming and Linear Programming with Several Objective Functions. *In: Fuzzy Sets and Systems* 1, 45-55 (1978).
6. Zimmermann, H.-J,.Fuzzy Set Theory-and its Applications. (Fourth Edition), Boston (2001).
7. Zimmermann, H.-J, Computational Intelligence in Logistics. *In: D.B. Fogel, CH.J. Robinson (edtrs): Computational Intelligence, The Expert Speak. IEEE Press Piscataway, NJ (USA)* (2003).
8. Zimmermann, H.-J., Dorndorf, U., Herbers, J., Panascia, E.: Ports o'Call for O.R. Problems, *in: OR/MS Today April* (2007).