EVOLUTIONARY METHODS FOR DESIGN, OPTIMIZATION AND CONTROL
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APPLICATIONS OF EVOLUTIONARY METHODS FOR COMPLEX INDUSTRIAL PROBLEMS

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Abstract. Adaptive Business Intelligence systems combine the methods and techniques that enable prediction, optimisation and adaptation. Adaptive Business Intelligence software solutions powered by Computational Intelligence tools are invaluable for making better predictions and decisions. This paper discusses applicability of Adaptive Business Intelligence software systems for Demand Planning, Advanced Planning and Scheduling, and Supply Chain Network Optimisation, developed by SolveIT Software Pty Ltd.

Key words: computational intelligence, optimisation, scheduling, planning, evolutionary algorithms, global optimisation, multi-silo optimisation

1 INTRODUCTION

In recent years production-based businesses have been under enormous pressure to improve their top-line growth and bottom-line savings. Hence, many companies are turning to systems and technologies that can help with: Demand Planning, Advanced Planning and Scheduling, and Supply Chain Network Optimisation.

Demand Planning (DP) is the process of forecasting what future demands may be. This is important as it allows companies to be sufficiently prepared (in terms of inventory) for their customers. More accurate demand forecasts can result in fewer backorders and reduced inventory carrying costs as well as other benefits.

Advanced Planning and Scheduling (APS) is the process of optimally allocating raw materials and production capacity to meet demand. This is important as it allows companies to perform detailed scheduling in highly complex production environments. Additionally, it allows for automatic optimal rescheduling (adaptation) in response to unexpected events such as machine failures or electrical outages.

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Supply Chain Network Optimisation (SCNO) is the process of making optimal business decisions about the design and operation of a supply chain network. This is important as it allows companies to cut transportation costs and stock outs across the supply chain as well as optimise current inventory policies and sourcing strategies. SCNO solutions can assist companies in making globally optimised (company-wide) decisions, rather than locally optimised (silo-based[4]) decisions, and improve management's understanding of business-specific rules and their impact on supply chain activities.

For complex planning, scheduling, and optimisation activities - especially those that are heavily constrained or require multi-stage scheduling and frequent re-scheduling - our experience is that off-the-shelf software solutions just do not work. Because of the many differences between problem types and industries, a company often ends up with a rigid system with preset objectives, logic, and scope, and which does not fit their core operation in a changing environment.

2 ADAPTIVE BUSINESS INTELLIGENCE SOFTWARE SOLUTIONS

Computational Intelligence methods are very well suited for powering Adaptive Business Intelligence software applications for DP, APS, and SCNO. Many methods (e.g., agent-based systems, ant systems, evolutionary algorithms, fuzzy systems, genetic algorithms, neural networks, rough sets, swarm intelligence, simulated annealing, tabu search) have already been incorporated into software applications that bring companies millions of dollars in return on investment. Furthermore, products based on Computational Intelligence usually are more robust in handling of non-linear relationships and dynamic environments.

Adaptive Business Intelligence software solutions for DP, APS, and SCNO fall into a broad area of "decision support systems" in information technology. Today, this area is more important than ever. Working in dynamic and ever-changing environments, modern-day managers are responsible for an assortment of far-reaching decisions: Should the company increase or decrease its workforce? Enter new markets? Develop new products? Invest in research and development? The list goes on. But despite the inherent complexity of these issues and the ever-increasing load of information that business managers must deal with, all these decisions boil down to two fundamental questions: *What is likely to happen in the future? What is the best decision right now?*

Whether we realise it or not, these two questions pervade our everyday lives - both on a personal and professional level. When driving to work, for instance, we have to make a traffic prediction before we can choose the quickest driving route. At work, we need to predict the demand for our product before we can decide how much to produce. And before investing in a foreign market, we need to predict future exchange rates and economic variables. It seems that regardless of the decision being made or its complexity, we first need to make a prediction of what is likely to happen in the future, and then make the best decision based on that prediction. This fundamental process underpins the basic premise of Adaptive Business Intelligence.

Simply put, Adaptive Business Intelligence is the discipline of combining predic-

[4]In this paper *silo* refers to be one of the components of the business, like distribution of goods, production of goods or supply of raw materials.

tion, optimisation, and adaptability into a system capable of answering the two fundamental questions cited above. To build such a system, it is necessary to combine the methods and techniques that enable prediction, optimisation, and adaptation.

Adaptive Business Intelligence software solutions are usually of high complexity, as they require solving highly constrained multi-objective optimisation problems set in dynamic environments. Many methods exist to address these issues, however, in this paper we will concentrate on just one aspect, namely high structural complexity of the problem, which results from a desire to perform "global optimisation" in business sense. We explain this further in the following section.

3 GLOBAL AND LOCAL OPTIMISATION FROM A BUSINESS PERSPECTIVE

Optimal production of goods, supply of raw materials, allocation of orders among factories, distribution and logistics are some of the examples of the real-world industrial problems. Each problem by itself is very complex, involving thousands of variables, non-linear and heavily constrained. Taking all this complexity into account, it becomes virtually impossible for deterministic systems or even (human) domain experts to find an optimal solution. Moreover, the manual iteration and adjustment of scenarios (what-if-analysis), which is needed for strategic planning, becomes an expensive, if not unaffordable, exercise. The use of Adaptive Business Intelligence methods, gives companies huge benefits, in terms of savings, maximisation of the profit, minimisation of carbon emission, waste or others goals. These methods give advantage of quickly solving problems within each silo of the supply chain on the current competitive market, especially within always changing dynamic environment that gives a very important feature of optimisation technique - adaptivity.

For large businesses, especially ones that involve optimisation among multiple silos, all its silos should be optimised. Many algorithms were developed to solve various supply chain problems in a single silo [2–4]. However, optimisation of each silo by itself without considering relationships with other silos may not lead to a globally optimal solution of the whole supply chain.

Consider an example in which a company produces and distributes certain types of goods. Suppose that the company's factory is very efficient and, in a given month, produces an exceptionally large quantity of finished goods. From a local point of view this component of the supply-chain operation (i.e. the factory) performed excellently. However, if we look at the broader picture of global production, if the excess goods are not readily distributed and consumed, the company will need to use storage space which will cost extra money, thus making this locally good production run sub-optimal from a global point of view.

This example shows that the concept of *global optimisation* may have different perceptions depending on which scope the problem is looked from. Traditionally, the problem of global optimisation (in the classical sense), is to find $\vec{x}$ so as to

$$optimise f(\vec{x}), \vec{x} = (x_1, \ldots, x_n) \in \mathcal{F} \subseteq \mathcal{S},$$

where $\mathcal{S}$ defines the search space and $\mathcal{F}$ defines feasible region which is bounded by the set of constraints. Optimisation of just production silo of the company, without considering distribution silo, is global optimisation from a classical perspective.

The search space in this kind of single silo problem is of relatively low cardinality. However, most of large businesses are interested in optimisation of the whole supply chain, not just a part of it - *global optimisation from a business perspective.* From classical perspective this multi-silo problem has more complex search space structure and number of variables is significantly larger.

The distinction between local and global optimisation from a business perspective lies in the differences of their respective search spaces. In local optimisation from a business perspective search space is usually constructed of a simple domain variables such as real numbers in case of numerical optimisation or permutations in case of combinatorial optimisation. The search space of a global optimisation from a business perspective typically has a more complex structure of several simpler search spaces. This type of optimisation can be thought of as optimisation of the optimisations.

When compared to classical global optimisation, business global optimisation takes advantage of the divide and conquer approach to simplify the overall complexity while still producing efficient solutions at the global level. This concept is somewhat similar to the concept of Object Oriented Programming that led to the new heights in software design. Simply, global optimisation from a business perspective is a new way of modelling the supply chain. Some characteristics of global optimisation from a business perspective are the following:

- *Dependence or partial dependence among components.* Problem specific constraints and business rules tie single components together creating dependencies among them. Note that constraints here can be *intracomponent* constraints, which apply to a single component itself and *intercomponent* constraints, that actually make these dependencies. Intracomponent constraints are the classic type of constraints. Intercomponent constraints have a slightly different purpose in global optimisation compared to the classic one.

- *Limited communication between components.* Separate components of supply chain are complex problems by their own, they have special goals, constraints, can even be of different nature. In some problems it is even impossible to have constant information exchange with the silo, and sometimes it makes the problem too complex to comprehend. It is an advantage in much the same way as information hiding and encapsulation. Without this limitation a problem becomes extremely complex to optimise, considering this limitation we can come to the right solutions in quicker and more intuitive way.

- *Different search space structures.* We can think about a global optimisation problem as several local optimisation problems plus one or more higher level problems that combine the lower level problems.

- *Two or more levels of optimisation.* As can be seen on the figure 6, optimisation of the whole system (top level optimisation) combines optimisation among silos (second level optimisation). If optimisation in each of the silos is dependent on smaller level silos this would yield even more levels of optimisation.

Advantages of the concept of global optimisation from a business perspective are as follows:

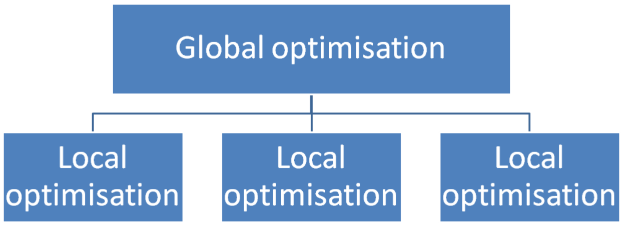

Figure 1: Two level optimisation

- *Pluggable architecture.* The framework of global optimisation from the business gives you advantage of plugging new silo or in some cases constraint without much affecting optimisation in the whole system. Hence, the global optimisation framework can integrate and reuse pre-existing silo optimisers while adding only communication channels. This allows a bottom-up approach (design, implementation and verification of local optimisers) and ensures modular testability.

- *Distributed computing.* The architecture of business global optimisation easily extends to a distributed computing platform.

- *Ability to analyse complex what-if scenarios.* Businesses and their competitors are rarely static. Instead, they are dynamic and the business environments are constantly changing. There is a large need for businesses to foresee how a particular change or decision will impact their priorities, profit and other objectives. The pluggable architecture allows a greater variety of what-if scenarios to be simulated and efficient evaluation of the global solution as what-if-changes are contained within a subset of the silos requiring only partial re-evaluation..

- *Structured point of view and ability to solve more complex problems.*

Consider an example where a company produces steel sheet at a single factory. Customers' orders must be batched and cut out of large rolls of steel in such a way as to minimise wastage. A broader version of this problem where the company has several plants that produce sheets of steel. Each type of steel can only be produced at specific plants: some can be produced at multiple plants, others at only one plant. At each plant the process of batching should be taken into account as described. In this case in order to maximise the profit of the whole company correct assignment of the orders must be done as well as optimal batching at each plant.

In the first case, the objective was to optimise operations of the single factory by producing and cutting rolls in an efficient way. In the second case, optimal batch cutting should still be considered this is just one level of optimisation. Just efficient batching would not guarantee globally optimal solution amongst the plants. Another level of optimisation should be applied - optimal allocation of orders (considering potentially lower manufacturing costs at other, more distant sites which may make up for higher distribution costs). Looking from this point of view the first case is an example of local optimisation from a business perspective whereas second one is the case of global optimisation.

We can clearly see some characteristics of global optimisation mentioned above, such as *two level optimisation* (See Figure 1). Treating each plant as a separate component we can observe *partial dependence between components*. Each plant is independent to a certain extent, it has its own duties, jobs to finish. But in order to achieve a globally optimal solution each plant needs to report to a general manager of all plants. This shows us another property - *limited communication between components*. Plants do not communicate with each other, they also do not send all information to a global manager of the company. This example also shows *partial dependence between components* characteristic.

Implementation of the global optimisation from a business perspective can be based on different approaches, for example divide and conquer, cooperative coevolution [1], agent based systems, swarm intelligence.

From an abstract point of view, business-perspective global optimisation fits into the framework of traditional global optimisation. What distinguishes it as a subclass from traditional business optimisation scenarios is that its problems can be formulated as objective functions with more complex-structured search spaces. For example, whereas a traditional problem might have the set of permutation of a finite number of objects as its search space, a business-perspective global optimisation problem might have as its search space the vector space of n elements, each of which is taken from the space of permutations of a finite number of objects (that is, permutation of locally permutated objects). We believe that this abstraction will be useful for studying global optimisation problems by allowing the dependence or partial dependence among components to be investigated in a more controlled setting. It would also permit researchers to examine subtle properties of such systems. Our future work will be based on such conceptualisations.

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REFERENCES

[1] Kenneth De Jong and Mitchell A. Potter. Evolving complex structures via cooperative coevolution. In *Proc. on the Fourth Annual Conf. on Evolutionary Programming*, pages 307–317, Cambridge, MA, 1995. MIT Press.

[2] Clarence H. Martin, Denver C. Dent, and James C. Eckhart. Integrated production, distribution, and inventory planning at libbey-owens-ford. *Interfaces*, 23(3):68–78, 1993.

[3] F. Elizabeth Vergara, Moutaz Khouja, and Zbigniew Michalewicz. An evolutionary algorithm for optimizing material flow in supply chains. *Comput. Ind. Eng.*, 43(3):407–421, 2002.

[4] Gengui Zhou, Hokey Min, and Mitsuo Gen. A genetic algorithm approach to the bi-criteria allocation of customers to warehouses. *International Journal of Production Economics*, 86(1):35–45, October 2003.