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From Morphological Analysis to optimizing complex industrial operation scenarios

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ABSTRACT

This article describes a method to generate, analyze, and optimize complex industrial operation scenarios. The model is based on a hybrid architecture incorporating two phases. The first phase accomplishes information acquisition and representation whereas the second phase imposes an optimization process on the collected datasets to generate an optimum state situation for a given industrial scenario. In the first phase, Morphological Analysis is used for breaking down complex industrial systems into manageable fragments. These provide the basis for knowledge and data acquisition and their representation. Each subset is represented in an individual table and defines one characteristic of the system like all kinds of resources, logistics, tax regulations, etc. In the second phase, the morphological table attributes are considered as variables which are subject to optimization. Values are assigned to all variables targeting a global optimum state. The solution reflects an optimized operation scenario for the relevant industrial organization. In the model, tables are linked by means of an objective function. The applied non-linear optimization process uses a hill-climbing algorithm. Due to certain constraints, all the volume demands at sales locations must be matched with the entire production capacities at production facilities. At the same time, either costs are minimized or profits are maximized. Additional constraints are imposed on the model to define feasible solution spaces. Both Morphological Analysis phase and the optimization processes employed have proved to be feasible and effective.

1. Introduction

1.1. Problem definition

Industrial operations are well-organized processes. Enterprise resource planning (ERP) systems are used to map the processes in the digital world. These systems provide tools to handle workflows, project management, collaboration, accounting, controlling, reporting, and other tasks. ERP systems assist in the collection, storage, management and interpretation of data regarding business activities and can map them into cost units, cost centers, time lines, task lists, etc. They are a means of generating ordered and/or filtered datasets, of producing reports, of sending notifications to team members, of tracking task lists and much more. However, these systems offer very limited services in the areas of business development and optimized industrial operation scenarios. This article introduces a method for optimizing such complex industrial operations.

Large industrial organizations have various administrative, production, and sales locations. They can be spread over several countries or even continents. Their operations are affected by a number of cost factors. In economic terms, the various locations are defined via cost centers where related costs are accumulated. Cost units are selected partial costs of products, which are standardized and used for comparing manufacturing sites.

Both planning and decision making are difficult issues. Their analyses depend on a large number of influencing factors and exceed the capacity of a human decision maker. In response to this fact and due to the lack of adequate methods and software systems, a new method has been developed and implemented.

1.2. The objective

The objective was to develop a method providing a practical approach to optimize business scenarios. This is to identify the savings capacities within complex industrial operation scenarios. There was a strong demand for methods, procedures, and software tools that would acquire data, analyze collected data, and improve operations for lowering production cost or for increasing profit.

The following goals have been defined:

- *Minimizing cost.* In this case, profit margins are not included in the analysis. Procuring, handling, storing production materials, manufacturing semi-finished and final products, distribution, country-specific regulations, tax specifications, depreciation allowances, cost of sales, etc. are the included cost units. The cost model is subject to a minimization process.
- *Maximizing profit.* Here profit margins are included and market prices that can be achieved in various regions, or countries, etc. are reflected. Profit is defined as turnover minus cost (see above). The profit model is subject to an optimization process.

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- *Performing unit cost calculations*. This modus operandi allows for calculating the cost of one unit of a product based on a given production site and sales location. The sum of all considered cost units is the total cost. All feasible combinations of production and distribution locations are considered. Comparing the outcome of these calculations based on all possible combinations allows to asses preferred cost-to-market arrangements.

The following crucial issues were identified for finding answers:

- Determining the production sites with profitable cost structures where additional investment for higher capacities would further improve the optimized scenario.
- Allocating feasible production quantities to advantageous production facilities.
- Pinpointing production facilities which operate under inefficient conditions.
- Relocating practicable production quantities from inefficient production sites to efficient ones.
- Building a model for performing the unit cost calculations for all manufacturing sites as cost-to-market at individual sales locations.
- Developing a software tool capable of solving the above issues.

1.3. Problem solution

The goals are met by shifting production quantities among production facilities and, thereby, either minimizing cost or maximizing profit. The problem is well-structured in accordance to Newell's set of criteria (Newell, 1969):

- It can be described in terms of numerical variables, and scalar and vector quantities.
- The goal can be specified by means of a well-defined objective function to minimize cost or to maximize profit.
- There are algorithms or routines that can be applied on the model for generating optimum solutions.

There are two major phases in optimizing complex industrial operation scenarios. The first phase is critical and comprises data and knowledge collection. As this input is usually submitted by different departments from various locations, its standardized specification is important. Data structures are subdivided into cost units which can be dealt with more easily. They become the input for the later optimizing process. Thereby, complex industrial relationships are divided into smaller entities which can be dealt with. Cost units are commonly used in accounting and controlling and, therefore, have been chosen for the collection of input data here as well. Morphological tables have been identified as the most suitable tool in the process of collecting, classifying, and preparing data for later analysis.

The second phase deals with optimizing scenarios. This is setting up an optimization model based on the set of information that has been collected beforehand. It employs a classical non-linear optimization algorithm based on an objective function and a set of constraints. It changes the value of decision variables towards an optimum state solution. This then reflects the solution strived for.

A large class of industrial operations can be modeled with the above approach. The method was originally developed for optimizing the complex industrial operation scenarios of a large construction material production and distribution company in Austria.

2. State of the art

Morphological Analysis is an established and practical method for acquiring and representing data and knowledge. Assisted by a generation mechanism which can be referred to as synthesis, the method can explore solution spaces by combining sub-elements to a final larger design entity.

First, complex problems are divided into sub-problems which can be considered separately. Zwicky adopted this ancient method and applied it to the analysis of technical systems (Zwicky, 1948, 1962, 1969). Strict Morphological Analysis defines data representation by means of morphological boxes with rows and columns. Usually, data can characterize the topology of shapes which are components and/or sub-elements of a larger structure. While table rows represent design attributes, columns represent associated values. Other types of data could reflect qualitative domain knowledge, material information, or generic and/or symbolic problem characteristics. Ritchey from the Swedish Morphological Society has further developed the objectives of Morphological Analysis in the context of problem analysis and synthesis (Ritchey, 1991). Furthermore, Ritchey points out the way to use Morphological Analysis in combination with other methods (Ritchey, 2009), either as follow-up or as preceding step. He suggests that "*In the latter case, the results of a morphological model can provide input for the development of other (possibly more complex) models.*"

Arciszewski elaborated on Zwicky's method and introduced more specific assumptions. Thus he created a complete methodological foundation (Arciszewski and Pancewisz, 1976; Arciszewski and Kisielnicka, 1977) which implies the concept of division and integration (Arciszewski, 1988). A formal representation of this modified and much more advanced approach has been published by Arciszewski (2016). His extended approach is based on eight assumptions which define how to subdivide a problem into small units and how to present these in a table. An abridged version is given here:

1. A closed-world approach is used to acquire domain knowledge and to store it in morphological tables.
2. A design concept of an engineering system is described by a finite number of symbolic attributes and their values.
3. Each symbolic attribute identifies a different abstract feature of a design concept of the future engineering system.
4. Any complex problem can be subdivided into a finite number of elementary sub-problems which cannot be subdivided any further.
5. Each sub-problem must be considered independent from the remaining sub-problems and their relationships are suspended.
6. All sub-problems (and their solutions) can be systematically represented in a single table that consists of a number of rows and columns.
7. Each row in the table is temporarily considered independent from all other rows.
8. Each table row stands for an elementary sub-problem represented by a symbolic attribute and a number of feasible values.

Assumptions 9 and 10 are concerned with the reverse process - the (re-)integration of solutions:

9. Any potential solution is represented by a sequence of attribute values from all rows in the table.
10. The random generation of combinations of attribute values leads to an unbiased potential solution.

A four-stage procedure defines the complete sequence from stage 1 (problem identification and formulation), stage 2 (analysis), stage 3 (synthesis), to stage 4 (presentation of results). Each stage is subdivided into additional individual steps. Morphological Analysis can be applied in many ways from generating innovative yet unknown solutions to reproducing well-known solutions which do not reflect innovation.

Joining attribute values yields individual solutions. Only one attribute value per row can be selected for generating a particular solution. Connecting select values with lines visualizes such a complete feasible solution as a vertical path through the table. The number of solutions is restricted by constraints imposed to prevent the generation of infeasible combinations. The number of paths in the table equals all possible