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Progressive modeling—An enabler of dynamic changes in production planning

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ABSTRACT

The prevalence of change propagating from the market conditions to the lowest level of functional activities of Manufacturing Planning and Control (MPC) systems, and vice versa, urges a commensurate supportive modeling approach. Progressive Modeling – a novel and integrated problem solution approach – is introduced to handle the new challenges resulting from the dynamic nature of today's manufacturing environment. It analyzes and decomposes the problem into several interacting components, builds a change-ready mathematical model and optimizes its solution. Aggregate production planning problem with a numerical example is used for demonstration and illustration.

1. Introduction

The prevalence of change and how it propagates form the outermost scope of business strategies to the lowest level of functional areas of Manufacturing Planning and Control (MPC) systems, and vice versa, requires more dynamic and adaptive modeling and analysis approaches. Progressive Modeling (PM) is proposed to handle a class of ill-formulated industrial production planning and control problems and new challenges arising due to the dynamic nature of today's manufacturing environment.

The proposed approach adopts the concepts of Component-Based Software Engineering (CBSE) [1] to analyze MPC problems (or more precisely systems) and decompose them into several fundamental interacting components. Every MPC system is analyzed from this perspective to define its components and define their functions and models, link the overall model to its solver and control the whole process. It presents the developed solution(s) in an appropriate format to the decision makers to help them to monitor, promote and optimize the whole system performance.

For every system component, a set of interfaces, which represents sub-set of the specifications of the system, or problem under study, are defined. The componentized nature of developed system emphasizes the model design, functionality and modularity, and de-couples their detailed implementation. This allows implementations to be updated to reflect model changes to be commensurate with variations in the MPC system.

The mathematical model specifications go beyond what is known as model assumptions by introducing the concept of assumption relaxations. This represents one of the basic requirements to make developed models more realistic and ready to be re-modeled or updated in the future as conditions or boundaries are changed. A set of objectives should be defined a priori, regardless of the subsequent evaluation methods (e.g. linear or non-linear). Similarly, constraints and their formulation may be added, modified or removed readily, and variables can be integer, binary, or real numbers. Non-linear, rather than linear, modeling is used as the default.

Intelligent optimization techniques, such as Genetic Algorithms, Artificial Neural Networks and Tabu search, are the typical solution algorithms. Unlike exact methods, these techniques are loosely coupled with the problems and their assumptions and their capabilities can be independently up-graded as needed as better solution algorithms become available.

The underlying premise behind Progressive Modeling is that developed MPC system or sub-systems weave developed models and their linked solution algorithms into several interacting components which should be useable for a wide range of problem variants and capable of optimizing the modeled system performance rather than optimizing a problem solution.

1.1. Propagating the balance: PM Governing philosophy

Changeable manufacturing [2,3] was introduced as an umbrella concept that embraces the ability of manufacturing systems to change and react to changes. Changes in manufacturing propagates from markets to products, manufacturing system, process planning, Manufacturing Planning and Control (MPC) and enterprise organization. The changes on these multiple fronts do not occur in isolation but are often interdependent. The real challenge is to reach and maintain a balance among all criteria to stay competitive in today's turbulent manufacturing environment. Companies strive to excel at the strategic scope and strategic strength dimensions in order to achieve a competitive advantage. The strategic scope focuses on the composition and size of the target market and strategic strength considers the core competencies of the manufacturing enterprise. There is a clear shift from taller hierarchies to flatter and matrix-like organization structures to improve responsiveness and autonomy and increase the ability of manufacturing enterprises to address these changes. Product-wise,

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adopting economies of scope (versus economies of scale) places certain constraints on the design of manufacturing systems and their production control strategies. Mass-customization is growing rapidly with serious attempts to lower prices. Companies now compete on being both responsive and efficient. A mix between agile and lean practices is essential to fit these new requirements. Advances in manufacturing technologies move the changeability boundaries and its limits forward, i.e. reconfigurable manufacturing systems (RMS) with its incremental change of functionality and capability versus Flexible Manufacturing Systems (FMS) with built-in abilities to change its functionality within a pre-defined scope. The future changes and evolution of RMSs is by definition uncertain at the outset; it changes based on market and products requirements, and needs a co-evolving MPC system to effectively address its needs. MPC systems represent a gateway between the manufacturing system resources or supply side and its environment (i.e. market or demand). The ability of an MPC system to capture and achieve the balance between those competing goals is a real challenge. Maintaining the balance at all fronts (strategies, organization structure, products, technologies and MPC systems) and under varying conditions governs the driving philosophy of progressive modeling. The goal is to remove the restrictive and problem- or solution-specific constraints and embrace modular component-oriented design to provide future possibility for modifying or replacing any function or module without changing the pre-designed and streamlined system structure and components' interaction protocols and specifications. This approach maximizes the flexibility and changeability of MPCs in light of changes in objectives, models, solution methods and data. This newly developed progressive modeling methodology has been implemented and is applied in this paper to aggregate production planning as an illustrating example.

2. Related literature review

2.1. MPC systems: state-of-the-art

Dynamic, uncertain, and complex structure nature of MPC systems and how they respond to market needs and drive the underlying manufacturing process to meet them in a well differentiated way inspired many researches to resort to untraditional approaches to address them. Emergent Synthesis [4], Holonic Manufacturing [5], Control-theoretic approaches [6,7], Agent-based systems [8], Supply networks [6,9], and Changeable manufacturing [2,3,10] are some examples. Progressive modeling is a new approach that combines several principals of software engineering, optimization, mathematical modeling, artificial intelligence, operations research and business concepts to make the MPC modeling more practical and ready for change. Some elements, characteristics, and enablers of changeable MPC [2,3,10,11] focusing on high-level system characteristics in general have been introduced recently. Progressive modeling, in contrast, provides the ability to implement a comprehensive, detailed and more specific modeling and updating at the narrower scope of the individual components and relationships.

2.2. MPC systems architecture

Over the last few decades, several MPC frameworks and architectures have been developed. The work reported focuses on building integrated MPC systems that automate the manufacturing planning, scheduling, and control process. Most of these frameworks can be characterized as either Decision Support Systems or Automated MPC Systems [12,13]. Object-Oriented MPC frameworks [14,15] suffer from being only modular at the logical and hierarchical levels, which makes them inadequate for changeable MPC systems since any update would mean that the whole system should be replaced. The MPC system components should evolve independently to address the continuously changing market needs, manufacturing system and processes. Component Based Software Engineering (CBSE) provides the tools and the power to address this basic characteristic. The motivation for breaking down the MPC system into multiple components is to loosen the coupling between these components and increase their capability to evolve independently. Since a component-based application consists of a collection of building blocks, any component can be added or removed as needed. When a component implementation is modified, the changes are confined to that component only. No existing client of the component requires re-compilation or re-deployment.

2.3. Aggregate production planning

Aggregate production planning (APP) is a mid-term capacity planning system responsible for transforming forecasted sales and system resources (machinery and personnel) into feasible operation plans for the following 6–18 months. The goals of production planning are to define a combination of production rates, inventory patterns, workforce levels, reduce production costs, achieve required customer service levels, smooth-out resource fluctuations, and maximize resources utilization. Development of production plans starts with identifying the long-term objectives, analyzing existing marketing strategies and estimated demand, analyzing available resources and adjusting them to meet the fluctuating demands. Production operation plans and resource schedules that are able to hit a balance among all these objectives represent a real challenge in the existing turbulent environment. Nam and Logendran [16] conducted a survey of APP techniques and identified the most frequently used techniques including: (1) Trial and error methods, (2) Graphical techniques, (3) Parametric production planning, (4) Production switching heuristic, (5) Linear programming, (6) Goal programming, (7) Mixed integer programming, (8) Transportation method, and (9) Simulation models. More recent research adds AI optimization, Decision support systems, and fuzzy logic to the list.

Stockton and Quinn [17] analyzed existing models limitations and solution techniques and pointed out that: 'None of the existing APP techniques can identify optimal or near optimal plans for real world problems that involve a range of planning variables.' Also, those techniques that can identify optimal plans do so by achieving only cost-related objectives ignoring many other non-cost objectives often sought by managers. In addition, within many organizations the cost relationships used by these methods do not adequately represent actual costs. The mathematical procedures used by existing methods are also complex; hence managers are often reluctant to use such techniques in practice. The proposed progressive modeling approach addresses these shortcomings in addition to the need to adapt, incrementally and progressively, as needed and when needed, to the frequent variations and changes.

3. Progressive modeling

The progressive modeling approach can be summarized into three main steps: Analyze and define the components the problem at hand, build the mathematical model, and define the solution methodology. An aggregate production planning problem is used as an example to illustrate these principles. The remaining parts of this paper show in details how these principles are applied and the significance and new potential applications introduced by that the proposed progressive modeling to the industrial research field.

3.1. Analyze and componentize the problem at hand

Aggregate production planning system is visualized as an MPC component that keeps the balance between the manufacturing system resources and its output represented by products as depicted in Fig. 1. Using the CBSE principles, the APP system is decomposed into several interacting components: Modeler, Products, Workforce, Machinery, Optimizer, and User Interface.