Controlling Customer Orders in the ETO/VUCA Contexts

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Abstract. Under hyper-competition customers expect to accept last-minute changes in their orders. In such circumstances ETO manufacturing exhibits the VUCA specificity and suffers from many issues like delays, excessive costs, low quality etc. This paper examines operative controlling as a mean to facilitate discovery and response to the changes and disturbances. The approach derives from the phenomenological research and the reflection on theory and practice. The solution uses an integrated model that represents all workflows subject to changeable contexts and is based on three pillars: (i) run-time data extraction; (ii) integrated representation of workflows; (iii) providing current information to shareholders. The concept was validated by prototyping and a use-case.

Keywords: ETO manufacturing, VUCA, Operational control, Changeability.

1 Introduction

Manufacturing industry is increasingly facing the requirement to deliver high variety of customized products in very low volumes. Under hyper-competition customers are reluctant to compromise product long delivery and specifications, but rather expect to accept even at last minute changes in their orders. Thus, the context of engineering-to-order (ETO) tends towards the VUCA (volatility-uncertainty-complexity-ambiguity) specificity [1]. It can be summarized as follows [2]:

1. Customer-order specifics penetrates backward the activities of value stream; this happens in a variable way: from parent to child orders and within singular orders;
2. Parallel engineering, purchasing, subcontracting and manufacturing is a must; purchasing or even manufacturing must be started before products and processes are fully engineered; cross-functional and cross-processual dependencies are multiple, complex and elusive; despite this orders, products, processes, costs and quotations have to be parametrized right at the first time;
3. Frequent changes in customer order specifications occur; they are often missed or misinterpreted and hard to track; together with the processual complexity of production support, this causes frequent errors that are difficult to discover; altogether the state of affairs becomes vague; sharing current engineering and operational data, both internally and with subcontractors, becomes very difficult.

In such conditions, engineering, production planning and control (PPC), purchasing and quality assurance, require more effort and time and are less robust. The causes are the need to multiple re-work and reliance on incomplete or Small Data. Thus, the outputs of these activities (process plans, material and time standards, schedules, quality specifications, etc.) are less accurate, often fault and late. The failures, starting from customer order specification until delivery and installment of products, are hard to discover because the legacy systems (CRM, CAD, PLC, CAE, ERP, MES) provide a limited visibility across functions and processes. Analyzing effects and responses to the changes and distortions, like announcing them, is difficult. Ultimately the compliance with specifications, punctuality, quality, productivity and costs are deteriorated. The perpetual change in customer orders significantly enhances the VUCA features.

The aim of this paper is to explore the potential of operative controlling as a means to deal with the change along execution of customer orders and the side-negative effects. The targeted management functions are quick exposure of change and early warning of threats. Another important function is facilitating the development of responses to the emerging issues. The approach derives from phenomenological research and existing knowledge, including theories of: ETO manufacturing [3, 4, 5, 6, 7], PPC [8, 9, 10] and operations research [11]. The solution aims at overall visibility and applies integrated model of customer orders fulfillment which enables the control of all workflows affected by the emerging change and disruptions. The framework is built on three pillars: (i) run-time data extraction, whether from legacy systems or dedicated means; (ii) augmenting reality subjected to decision making through cross-functional and cross-processual representation of all workflows related; (iii) continuous dissemination of information about changes and their likely consequences.

Basically the tool based on this model is intended as an overlay to legacy systems, using their data. It can be also developed into an independent solution using dedicated data sources. The model should be used by relevant organizational routines. The solution was validated by a use case supported by a developed prototype software tool.

2 Literature

The key concept of ETO is customer order decoupling point (CODP), which was originally defined as the earliest point in a process where a product is designed for a specific customer [12]. This way the material flow along supply chain could be divided into two sub-processes: pre- and post-CODP. The latter requires individualized control of orders and pegging abilities, while the former may be based on replenishment. An extensive review of literature, which considers the supply chain context of ETO [3], suggests a spectrum of generic strategies including: integration [13], information management [8], re-engineering, time-compression and flexibility. Although all these strategies can to a certain extent support the ETO/VUCA context, a direct aid is given only by the information management strategy [8]. Some authors differentiate the engineering changes in ETO environment [15] and analyze their impact on material flows throughout the entire order fulfilment process [6]. Also the need for early warning of risks is suggested, like the approaches to identify their symptoms [16].

The need to differ perspectives in ETO by decoupling engineering and manufacturing was suggested in [4]. This approach has been extended by recognizing decision domains and degrees of CODP penetration [17, 18], dynamics of CODP location [5], and distinction of resource and process related decoupling [17].

The literature assesses the use of existing PPC methods and systems for ETO manufacturing [8, 9]. In general, poor match is pointed out between the specificity of ETO (dynamics, uncertainty, complexity) and its needs for the decision support, with the abilities of MRP/ERP [5]. Some authors even suggest uselessness of MRP/ERP for the ETO manufacturing [8, 18]. They indicate such shortcomings as [8]: (i) inability to cope with incomplete or uncertain information at the early stage of order execution; (ii) non-suitability of capacity planning for ETO; (iii) inability to operate non-physical processes. Actually some ERP systems are equipped with functions that reduce these shortcomings. The critic does not consider the often needed traceability of parent or child orders. For this purpose many systems offer the indented tracking and pegging.

Heterogenous approaches to production planning are also hybridized (e.g. the project approach and the overall framework of PPC [9]). What MRP/ERP systems are not able to effectively operate is the horizontal integration through linking of planned workflows and items. Thus, the support to cross-functional and cross-process coordination of customer orders is not possible. Also the correspondence of cycle times (lead times) and workloads (rough processing times) is an Achilles heel of MRP/ERP.

The interest in the applicability of MES systems to ETO context is limited. MES systems generally focus on the field. They are not directly affected by the CODP-related type of manufacturing, but rather by the approach to shop-floor control, the complexity of material flows, the degree of automation and the layout of resources. Arbitrating about suitability of MES systems for ETO manufacturing is risky because of the diversity of conditioning. Hybridization is normally an imperative therein.

Some authors propose the frameworks for PPC in the ETO context. One of the approaches is based on distinction of four decision categories: driving (why and when flows are initiated), differentiation (uniqueness of flows), delimitation (triggering flows) and maintaining transparency of workflows using basic BOMs [18]. Process and resource decoupling is applied and various lead-time contexts, i.e. types (internal vs. external, adapt, delivery and supply) and their relating. Another framework learns from the particular VUCA aspects of ETO, the rules of PPC, and the structuring of ETO manufacturing (identifying the generic items of material flow control, and the production phases) [8]. Following that four generic ‘production units’ are proposed: conceptual design, product engineering, component manufacturing and assembly.

The need to hybridize production situations in information systems was also examined, considering various factors such as [5, 9]: demand variability, disruptions, and specific complexity factors. The framework proposed in [5] considers the following ‘hybridizations’: (i) different types of manufacturing (ETO, etc.) in master production schedule; (ii) merging ‘order requirements planning’, ‘project requirements planning’ and ‘project capacity planning’ with standard MRP functions; (iii) differently aggregated product data; (iv) various generic data (routings, pricing structures and budgets). Network planning is assumed as basis to scheduling, planning materials and capacity, monitoring progress and accounting costs. Another hybrid approach assumes integration of aggregate demand management with preliminary engineering by using the standard MRP functions and project planning [9]. The customer changes are controlled along the project planning and scheduling by using the pegging function. This way re-costing, re-budgeting and re-quotation are enabled.

Despite the abundance of ETO literature, only few papers address the issues related to the VUCA context and the use of controlling customer orders as a countermeasure against the negative effects. Such aspects as customer change management, links of activities in different functions or domain ambiguity, are considered to a limited extent, if at all. Existing knowledge and solutions provide only limited support for the ETO/VUCA context, especially in regard to the customer changes. Nevertheless, literature recognizes the need to apply multi-perspective viewing of the domain and hybridize different production situations within the integrated functionalities of PPC.

3 Phenomenology of Change in Customer Orders

This section examines the phenomenology of changes in customer orders along their execution. The aim is to develop a base for a suitable domain representation that could be used by the controlling framework. The following functions of a firm may be affected by the customer changes: sales, engineering, PPC, purchasing, manufacturing, internal logistics and accounting. If the decoupling zone [4] goes beyond the boundaries of a focal organization, suppliers (subcontractors or partners) are external stakeholders of the changes. The items subject to cascading changes are: (i) engineering orders, items, workloads, cycles; related tasks or schedules; (ii) manufacturing items, workloads, capacity loads, orders and schedules; (iii) purchasing items, orders and schedules; (iv) costs, budgets; (v) quotations and due dates in customer orders.

The sequential view of customer order execution which shows the cascading of changes is presented in Fig. 1. Lifelines represent organizational functions and provide multi-perspective view of the domain. Sequential and causal dependencies can be both considered. Another wave of changes is driven by faults and disruptions. Faults may stay undiscovered for a long time. If not discovered they result in disruptions and losses. The typical causes for them are miscommunications or mistaken actions and items. Both disruptions and faults, like the cascading of customer change, require early warning. The symptoms subjected to tracking are: (i) actual and likely delays or speedups; (ii) missing or obsolete items (materials, work); (iii) under- or over-utilization of capacity; (iv) excessive costs or exceeded budgets; (v) impossibilities (e.g. assembly cannot be completed as input items are incorrect). The above conceptualization should be regarded as an adaptable reference, not as a rigid pattern. It provides the basic setup to tailor digital tools to support the controlling of customer orders. It also sets a reference to design organizational routines for the controlling.

Another factor of VUCA, which interacts with the cascading changes in customer order specifications is the successive disaggregation (explosion) of items subject to planning or execution, including: (i) product design; (ii) process plan; (iii) workloads and capacity loads; (iv) material requirements; (v) schedules; (vi) costs and budgets.

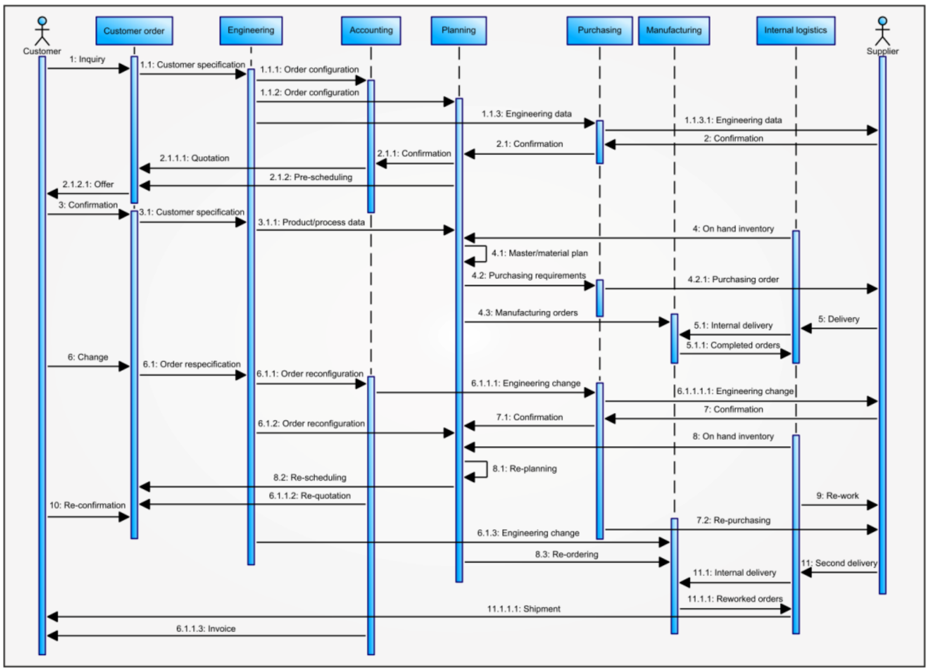

Fig. 1. Cascading of changes in customer orders

The third factor of VUCA in ETO is the dynamics of decoupling zones [18]. The range of customer order penetration may vary over time: along product life-cycle, from customer order to customer order, and from product to product. The fourth factor of VUCA in ETO relates to the common use of resources (materials, capacities) by different orders. Finally, industrial practices expose the role of holistic visibility, which is weakly supported by the legacy systems that mostly focus on the material flows and the capacity utilization. Consequently the ambiguity and uncertainty arise.

4 Integrated model of customer order fulfillment in ETO

This section outlines an integrated model of customer orders in ETO. The IT tool based on this model should facilitate timely and adequate responses to the arising changes in customer orders. The approach learns from the existing knowledge and recognizes the VUCA factors identified in section 3. It attempts to compromise three alternative ways to the possible IT support: (i) overlaying legacy systems; (ii) hybridizing existing models, systems or functionalities; (iii) applying entirely new approach. The first two approaches apply BOM-like structures or layered networks to represent: products, requirements, bills of capacities, engineering and manufacturing processes, bills of costs and budgets. The model applies ontological domain representation and follows the transformational paradigm by recognizing: outputs (tasks), activities (transformations) and resources [10]. The basic constituents are activities (Fig. 2).

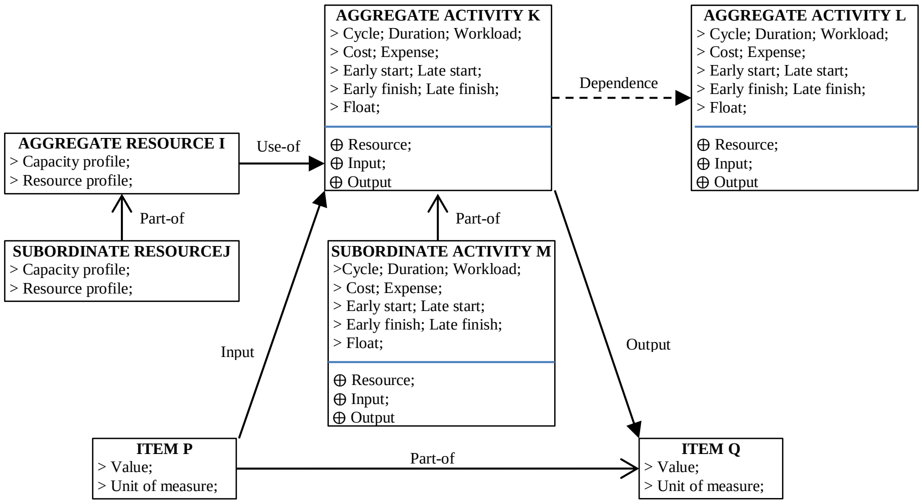

Fig. 2. Generic constituents for domain representation

Basically, but not obligatorily, activities have inputs and outputs, and engage resources. They are attributed with the parameters of workload, time, costs and expense. Resources are attributed with the capacity and load profiles. Both can be rolled up to aggregate resources or overall capacity factors. The basic mereology of resources and activities presumes distributive parthood relationships, which enables aggregation or decomposition, when needed and successively (in run-time mode). For this purpose the models of aggregation and decomposition presented in [10] (see: Figures 34, 33) can be adapted, accordingly. Costs can be subjected to additive accumulation, while expenses can be time-phased and rolled-up (additive forward accumulation). Time-phasing may follow various rules, like offsetting (backward) and forward timing. The early and late dates can be estimated, like the floats. The third category of nodes is items. Items are linked by the mereological relationships. The parthood relation is basically used to represent BOMs. It parallelizes the linked input and output relations, i.e. in reference to activities executing the parthood relation. Items are attributed with the values, which can be rolled up. Activities are also linked by the dependence relations, e.g. time dependencies (finish-to-start (FS), etc.). Backward and forward rollups of dates enable calculations of the early and late dates, as well as floats.

The proposed way of abstracting generalizes both, the distributive structures of bills (BOMs etc.) and the networks used for scheduling. It can represent all items subject to change in customer order specifications, which were identified in section 3. It recognizes the dynamics of decoupling zones and commonality of resources. It also enables to follow the symptoms of threats that are subject to early warning, and to identify the items affected by revealing events through tracking of dependencies. The proposed model can be equally used by various functions of ETO manufacturing. Through layering - by organizational functions - it supports cross-functional visibility. Layers represent the state of affairs in functions, while cross-layer dependencies secure the holistic view of operations. The viewing of layers is as follows. Manufacturing, logistics and planning views the related activities, resources and material items. Engineering views the related activities, resources, and engineering or material data items. Purchasing views the related activities, resources and material items. Accounting views the costs and expense. Sales view their activities and the contract items.

To benefit from the model organizational routines are needed: (i) supervision of data sourcing; (ii) monitoring symptoms subject to early warning; (iii) cascading changes or disruptions; tracking of subsequent effects; (iv) re-engineering, re-work, re-planning, re-purchasing, re-costing, re-budgeting, etc. Altogether the digital tools and organizational routines can facilitate early warning of threats, as well as development of appropriate responses to the changes in specifications of customer orders.

5 Case Study

A limited validation was performed based on a case study in KraussMaffei plant in Sučany (Slovakia). The factory engineers and manufactures customized injection moulding machines. The final assembly is takted (14 steps, each along one shift). Electrical control cabinets are made through fixed-station assembling. Components are fabricated, supplied or subcontracted. Such arrangement results in very simple structuring of the decoupling zones. The factory exploits SAP ERP as well as Camos CPQ (to customize, price and quote products). Both systems are integrated via Camos Connect SAP interface. The case fully reflects the specificity of ETO manufacturing.

After analysis, a software tool was prototyped by adapting the proposed model. It is an overlay to SAP and Camos. It implements timing calculations described in section 4 [2]. The data extraction from legacy systems is applied accordingly. Although the developed functions are basic, they can effectively facilitate early warning and enables timely responses to the arising changes and deviations. Multi-perspective viewing of the domain is provided. With this regard relevant organizational routines were also shaped. Further details of the validation are presented in [2].

6 Summary and Further Work

Integrated controlling of customer orders based on multi-perspective conceptualization of the decoupling zone was outlined in this paper. The layers of model represent key functions of production affected by the ETO environment, including engineering, planning, manufacturing, purchasing and logistics, and costing. The model entangles processual interdependencies, including the vertical precedencies and horizontal dependencies, as well as the influence relationships of effects that emerge due to changes imposed by customers or errors. The approach enables cross-functional transparency, which is crucial under the VUCA ETO conditioning. Operation of the model is based on the run-time data extraction, as well as sharing of the latest information and developed responses with all shareholders. The further work should focus on adaptation of various PPC methods, further detailing and diversification, considering inter-organizational aspects. The development issues provide another challenge.

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