An Agile Planning & Control Framework for Customer-Order Driven Discrete Parts Manufacturing Environments

M.F. van Assen

A&R Management Consultants

Levantstraat 34, 7559 CC Hengelo, The Netherlands

m.f.vanassen@wb.utwente.nl

E.W. Hans

Faculty of Mechanical Engineering, University of Twente

P.O. Box 217, 7500 AE Enschede, The Netherlands

e.w.hans@wb.utwente.nl

S.L. van de Velde

Rotterdam School of Management, Erasmus University

P.O. Box 1738, 3000 DR Rotterdam, The Netherlands

s.velde@fac.fbk.eur.nl

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Abstract

Agile manufacturing has become a major strategy to face stronger competition, the market pull and shorter product lifecycles. The key words in this strategy are agility and time-compression—the result of speed and dexterity. Surprisingly enough, most manufacturing companies still use hierarchical planning and control frameworks that are in principle utterly unfit to enable let alone support this strategy. In this paper, we present a planning and control framework for manufacture-to-order environments that enables and supports agile-based discrete parts manufacturing. The characteristic elements of our framework is that it is decentralized, logistics and business oriented, and that it recognizes that more detailed and more reliable data become available as orders advance through the different manufacturing stages and departments. Furthermore, it is a generic framework in that it applies to any discrete parts manufacturer, ranging from an engineer-to-order to an assemble-to-order company. We also point out the necessity of an organizational structure that supports and reinforces the framework. Particularly, we discuss the adoption and implementation of the new framework by creating multi-disciplinary teams and structural and operational supporting groups to strengthen the organization for agile manufacturing.

Keywords: Agile Manufacturing, Production Planning and Control, Framework.

Introduction

Stronger competition, the market pull, and shorter product lifecycles force manufacturing organizations to put customer service first and, as a result, to continuously improve their quality and reduce their lead-times. Agile manufacturing has become a major strategy to compete and to try and achieve sustainable competitive advantage in today's marketplace. The key words in this strategy are agility and time-compression—the result of speed and dexterity. Agility means being able to react quickly and dexterously to changing markets and customer needs, to produce high quality products, to reduce lead times and to provide a superior service. *Speed*, as a mechanism to achieve agility, that is, a short time-to-market and short lead-times, has been widely recognized as the equivalent of money, productivity, quality and even innovation (*cf.* Stalk (1988)). *Time compression* requires the searching for ways to compress time in all business processes, thereby revealing sources of quality problems and wasted efforts. Fixing these problems dexterously, results in higher quality, lower work-in-process, less waste of all sorts and thus lower operating cost. Agile-based manufacturing organizations increase productivity, gain customer loyalty and create a basis to outdo their competitors and, moreover, obtain favorable market shares; see for instance Blackburn (1991), Stalk and Hout (1990), and Suri (1994).

Vesey (1992) argues that speed is based on two premises: (i) an organizational environment where change and innovation come naturally; and (ii) technology that gives employees the most current, proven tools to perform their jobs. The latter also includes both information and communication technology. As material travels no faster than the information needed to produce the product, the speed of information that must be shared between manufacturing and supporting departments has become increasingly important for time compression. Communication barriers are often cited as the cause for lack of integration among functional areas, which is a major threat for time compression.

We subscribe to these two premises but stipulate a third premise: a *decentralized* manufacturing planning and control framework. Such a framework enables two necessities for time compression: first, the empowerment of (shop floor) employees to timely resolve disturbances and problems in the manufacturing process at the time and place they arise, in a flexible fashion; and second, a smooth, fast and flexible communication between and within primary and supporting departments.

Nonetheless, most production planning and control frameworks used today are either technical, or traditional. *Technical* frameworks are mainly designed for computer integrated manufacturing environments, particularly in discrete parts manufacturing, and as such they emphasize the technical aspects of manufacturing; see for instance Dilts *et al.* (1991). Recent developments on technical frameworks arise from research into fractal manufacturing (Warnecke, 1995), holonic manufacturing (Van Brussel, 1994, Christensen, 1994), bionic manufacturing (Okino, 1993), and intelligent manufacturing (http://www.ims.org). For a comparison of these more or less technical concepts, we refer to Tharumarajah, Wells and Nemes (1996).

However, as these concepts evolve from a computer-integrated manufacturing perspective, they strongly ignore logistics, socio-technical and business-oriented aspects, such as customer order processing and production planning; for this reason, they cannot really serve as a sole enabler for agile-based manufacturing. They have to be combined with frameworks that do take into account these aspects.

There are also what we call *traditional* frameworks; these frameworks were designed for manufacturing organizations with various functional areas and little interaction between them; see for instance Meal (1984), Smith (1989), Vollman *et al.* (1988) and Zäpfel and Missbaum (1993). Functional organizations do not aim at the integration of separate tasks and systems, but are based on *Taylorism,* which advocates distributed functional specialization as the way to increase overall efficiency. In these frameworks, all different manufacturing stages and departments are controlled by the same *hierarchical* planning and control model. This approach has two main disadvantages. First, low-level manufacturing planning decisions are made at a high aggregate level. As a consequence, low-level restrictions, e.g., precedence relations between activities, sequence-dependent setup times, and the availability of auxiliary tools and resources, are ignored. The production plan may therefore not be feasible let alone accurate at a lower level. It is often both time consuming and costly to fix the low-level coordination problems, since it usually leads to a combination of delay of orders and extra, last-minute efforts to finish certain orders in time, including overtime, hiring temporary personnel, or contracting out. Second, there is the requirement to specify detailed technical and logistic parameters early in the manufacturing process, since all manufacturing stages and departments that an order has to go through have to be planned in the very first stage, even if relevant data are not available yet. Consequently, uncertainty is embedded in low-level production plans in an early stage right away.

What is more, most hierarchical production planning and control frameworks, including MRP-II, use MRP concepts for capacity planning purposes; see for instance Vollman *et al.* (1988). In fact, MRP-II lies at the heart of most *Enterprise Resource Planning (ERP) Systems*, although it ignores fundamental production planning aspects such as finite capacity and variability, which is so characteristic of discrete parts manufacturing; see for instance Hopp and Spearman (1996). This is indeed remarkable: it is well known that the use of MRP-II leads to longer and longer planned lead-times, as a result of ignoring the interactions between work-in-process, capacity, variability, and lead-time. This phenomenon is known as the *lead-time syndrome* or *planning loop*; see for instance Zäpfel and Missbauer (1993), Suri (1994), and Hopp and Spearman (1996). Nonetheless, it cannot be denied that the introduction of an ERP system usually leads to lead-time reduction; a survey by Moret, Ernst & Young (1997) revealed that about 20% of the manufacturing companies experience a lead-time reduction of 10% or more. Hence, we cannot but conclude that this reduction is entirely attributable to the business process redesign, required to implement these systems, and which leads to a larger efficiency and a better information and communication structure; that ERP systems lead to lead-time reduction in spite of their MRP-II basis; and that further lead-time reduction would be possible if ERP systems would not use MRP for capacity planning purposes.

We conclude that neither technical nor traditional manufacturing planning and control frameworks are fit for agile manufacturing. In this paper, we propose a framework for discrete parts manufacturing that enables and supports agile manufacturing and that emphasizes logistic, organizational and socio-technical aspects.

Before we proceed, we first introduce our terminology. In this paper, we refer to *discrete parts manufacturing* as the generic term for any combination of engineering, production, assembly, and distribution activities involving discrete parts. Accordingly, a *discrete parts manufacturer* may range from an engineering company, via an engineer-to-order company, a 'jobber' to an assemble-to-order company and even a distributor. In the context of manufacture-to-order environments, distribution involves the storage of finished customer orders and their shipment; accordingly, a distributor is more a carrier than anything else. All activities of the same type take place in a *stage;* hence, a discrete parts manufacturer may consist of an engineering, production, assembly and a distribution stage. A stage may consist of several *departments*; for instance, the production stage may consist of a sawing, a machining, and a welding department.

Our framework is generic in that it consists of several general building blocks, with which it is possible to build the planning architecture of virtually any discrete parts manufacturer. In all cases, the framework has a central planning and control system that is responsible for customer order processing and long-term capacity planning decisions. *Decentralized* planning and control systems constitute further the planning and control architecture of the manufacturing organization. Each manufacturing stage, including engineering, production, assembly, and distribution, has its own planning and control system, or the different departments that together constitute a manufacturing stage all have decentralized planning and control systems. For instance, if the production stage consists of three departments, then either the production stage as a whole has a decentralized planning or control system, or each of the three departments has its own system. Each decentralized system is designed to help in solving disturbances in the manufacturing process when and where they arise, in a timely fashion. Nonetheless, the framework is designed such that consequences of a decision in one manufacturing stage for the other stages are taken into account.

The new manufacturing planning and control framework by itself is not sufficient to create an agile manufacturing organization; it is imperative that the organizational structure supports and reinforces the new framework. To this end, we propose the introduction and implementation of *multi-disciplinary teams*, *structural supporting groups*, and *operational supporting groups*. A multi-disciplinary team consists of representatives of each manufacturing stage, and its role is to monitor and manage accepted customer orders. Multi-disciplinary teams provide the necessary feedback, which contributes further to the smooth communication between manufacturing stages, departments, multi-disciplinary teams, and supporting groups. If economically possible, a product-oriented organization structure will emerge, where the borderlines between the manufacturing stages and departments are no longer present. The role of the supporting groups is to aid the manufacturing stages and departments to improve their manufacturing processes, systems, and performance. Currently, this concept is implemented in practice. Unfortunately, it is too early to report on the outcome, but first results are encouraging.

The organization of the paper is as follows. In Section 2, we present our framework and discuss its functioning in the engineering, production, assembly, and distribution stage. In Section 3, we give directions for implementation of our framework and discuss the role of structural and operational supporting groups. Section 4 concludes the paper.

A generic manufacturing planning and control framework

Basic principles behind the framework

To support agile manufacturing, we propose a new discrete parts manufacturing planning and control framework that integrates the functions of the different manufacturing stages that a product encounters throughout its manufacturing lead-time. It is a generic framework that can be applied to any discrete parts manufacturer. The basis of our framework is the observation that as a product goes through the different manufacturing stages, more detailed and/or more reliable product and process data become available. Current frameworks largely ignore this fact. In our approach, the planning and control of each manufacturing stage is based on the data that have become available up to this stage. Figure 1 provides a schematic overview of our framework. We first briefly point out the systems and modules of the framework and then further explain their working and interactions by use of an example.

The framework has three major components:

1. *a central planning and control system.*

   The central planning and control system takes care of customer order processing and the long-term capacity planning decisions.

2. *a decentralized planning and control system for each manufacturing stage.*

   All decentralized systems have the same structure: they all contain a planned order review module, a planned order release module and an activity control module. Together, these three modules take care of the planning and control of the manufacturing stage.

3. *an Information Management System.*

   All modules and systems are linked to the Information Management System (IMS), which has two main tasks: to manage the input and output of all modules and to take care of the feedback between the manufacturing stages.

Figure 1 suggests that each manufacturing stage has only one single decentralized planning and control system. However, as pointed out in Section 1, in case that a manufacturing stage consists of several departments that all need a decentralized planning and control system, we simply add one for each of these departments.

Take in Figure 1

As an example, consider now a company that engineers, produces, assembles and distributes certain types of products, and suppose that a price and a delivery due date of a specific product has to be quoted to a potential customer. To arrive at a quotation, three steps need to be made. First, a multi-disciplinary team needs to be assigned to the potential customer order, with the so-called process owners, that is, with members of the different manufacturing stages. Based on aggregate and/or estimated data, based on history, experience, expertise, similar projects in hand, procurement lead-times, and possibly some preliminary engineering, the team determines the estimated lead-times and milestones of the expected activities in each manufacturing stage. The quotation is further controlled by the central planning and control system. Its order review module uses data from the IMS, such as the current and expected future workloads and procurement plans and lead-times, and schedules orders to see if long-term capacity investments, for instance in expensive machines equipment or machines, are in order. The order release module carries out a rough finite capacity loading procedure. This module proposes an appropriate start date, a customer delivery date, as well as the corresponding internal due dates for the decentralized planning and control systems. The multi-disciplinary team uses all this information to quote and negotiate a competitive price and delivery date. Finally, if the customer accepts the quotation, then the order review module enters the accepted order into the IMS. From this moment onwards, the respective manufacturing stages are responsible for the planning and control of the order, subject to the internal due dates that were set in the order processing stage.

The decentralized planning and control system

Each manufacturing stage is controlled by a tailored decentralized planning and control system. All decentralized systems have the same structure: they contain a planned order review module, a planned order release module, and an activity control module. Short-term capacity investments decisions, including overtime, subcontracting, hiring temporary staff, are made on basis of the planned order review module. Note that the planning and control issues differ across stages; accordingly, the working of the planned order review module in one stage differs from the functioning of the same module in another. The modules of the decentralized planning and control systems retrieve and provide data from and to the IMS. Indeed, as pointed out in Section 2.1, the IMS serves as an information feedback mechanism, which provides each manufacturing stage with the right type of information concerning manufacturing and current workload conditions.

The planned order review module of each decentralized planning and control system converts the internal due dates that were set in the customer order processing stage into internal deadlines. Note that *a due date* specifies the time by which an order *should* be completed; a *deadline* specifies when the product *must* be completed. The conversion must take place on the moment that the order is released by the central planning and control system.

In the following subsections, we describe the functions, the goals and restrictions of each of the three modules in each decentralized planning and control system.

The engineering stage

The input of the planned order review module of the engineering stage stems from two sources. It includes the output of the customer order review module, including rough product specifications and the customer due date. It also includes aggregated information from the IMS, including current workload conditions of the engineering stage, available capacity, and requests from successive manufacturing stages, e.g., design for production requirements and design for assembly requirements. The planned order review module then matches expected engineering activities with the available engineering capacity, and if necessary, it proposes short-term capacity expansions such as overtime hours, subcontracted hours, and hours hired in. The internal due date now becomes a hard internal deadline for this manufacturing stage.

The planned order release module of the engineering stage releases all necessary engineering activities to the activity control module. A finite capacity planning module, i.e., a loading procedure, is used to make sure that all engineering activities are done in time.

The activity control module schedules and dispatches all engineering activities, and controls and monitors all dispatched engineering activities. Small disturbances are resolved locally, for instance by re-scheduling. Large disturbances must be resolved with the help of the central planning and control system, in concert with the decentralized planning and control systems of the manufacturing stages that may be affected by these disturbances.

To compress manufacturing lead-times, it is important that as soon as the engineering activities for a part or product are finished, the activities for this part or product in the next stage start without delay. This is particularly important if certain (sub)assemblies or components need to be purchased from third-party suppliers. The advantages are evident: this type of coordination not only decreases the manufacturing lead-time, it also speeds up the feedback to the previous stage, thereby creating a concurrent engineering effect. Moreover, the impact of the completed activities on the actual workload of the other manufacturing stages can be evaluated earlier and in more detail.

The production stage

The geometric and functional design as well as data from the decentralized planning and control module of the engineering stage serve as input for the planned order review of the production stage. It is also possible that the design specifications and other relevant data are directly obtained from the customer. This will certainly be the case for a 'jobber', who has no in-house engineering stage. In addition, expected capacity limits, current workload conditions and, if relevant, minimum procurement lead-times of raw material, obtained from the IMS, serve as input for the planned order review module.

The output of this module is an integrated production-process plan with technical and logistic process parameters for each order as well as detailed procurement plans, determined on the basis of the actual workload of the production stage. The planned order review module also matches activities from the production-process plan with the available capacity, and if necessary, it also proposes capacity investments. The planned order review module is in fact a capacity requirements planning (CRP) with the extra capability of making capacity adjustments if necessary. The module also works with internal deadlines.

The planned order release module is a finite capacity planning module, i.e., a finite capacity loading module, which carries out the loading subject to the process parameters specified by the production-process plan, the current workload situation and available capacity, and the internal deadlines of the planned orders. Furthermore, this module releases the activities to the activity control module, which schedules, dispatches, controls and monitors production activities and gives feedback to the planned order release module. Just as in the engineering stage, small disturbances can and will be resolved locally, e.g., by re-scheduling, whereas large disturbances must be resolved with the help of the central planning and control system and in unison with the decentralized planning and control systems for which these disturbances may have consequences.

The assembly stage

Information about the parts and components, produced in the previous manufacturing stage and/or procured from third-party suppliers, serve as input for the planned order review module of the assembly stage. Note that an 'assembler', with no engineering and production stage, gets these parts and components as well as the product specifications directly from the customer or suppliers. Again, expected capacity limits, current workload conditions, minimum procurement lead-times, and internal due dates serve as input for the planned order review module.

The output of the planned order review module is an assembly-process plan, based on the actual workload of the stage and the available capacity. This plan specifies the technical and logistic process parameters for assembly, the detailed procurement plans, and may also indicate that (short-term) capacity expansion, like overtime, is necessary. The planned order review module is in fact a capacity requirements planning (CRP), possibly with capacity adjustments. The internal due date now becomes an internal deadline.

The planned order release module is a finite capacity planning module, whose task it is to generate a feasible and efficient capacity plan, subject to the process parameters specified by the assembly plan, the current workload conditions, the available capacity, the internal deadlines, and the procurement plans and lead-times.

When an assembly activity has been released by the planned order release module, the activity control module schedules, dispatches, controls and monitors this activity and gives feedback to the release module. Disturbances are handled in exactly the same way as in the other manufacturing stages: small disturbances are handled locally, whereas large disturbances need to be handled by the central planning and control system, in harmony with the decentralized planning and control systems.

The distribution stage

In modern distribution, various aspects like warehouse management, integration of inventory and transportation, vehicle fleet management, and truck routing play an important role; see for instance Bramel and Simchi-Levi (1997). In our manufacture-to-order context, however, distribution is basically nothing else than the storage and sending of finished customer orders. Note that a distributor with no engineering, production or assembly stage is essentially a carrier, possibly with its own warehouse.

Information about parts, subassemblies or assemblies from previous manufacturing stages serve as input for the planned order review module of the distribution stage. Of course, a carrier gets this information directly from the manufacturer. Again, expected distribution capacity limits, current workload conditions, and internal due dates serve as input for the planned order review module as well. The output of the planned order review module is a distribution-process plan, based on the actual workload of the stage and the available capacities. This plan specifies the technical and logistic process parameters for distribution (including warehousing and storage activities) and may also indicate that (short-term) capacity expansion, like overtime, is in order. The planned order review module is in fact a capacity requirements planning (CRP) that proposes short-term distribution capacity adjustments if necessary. Internal due dates now become internal deadlines.

The planned order release module is a finite capacity planning module, whose task it is to generate a feasible and efficient distribution plan, subject to the process parameters specified by the distribution-process plan, the current workload conditions, the available capacity, and the internal deadlines. When a warehouse or distribution activity has been released by the planned order release module, the activity control module controls and monitors this activity and gives feedback to the release module. Disturbances are again handled in exactly the same way as in the other manufacturing stages: small disturbances are handled locally, whereas large disturbances need to be handled by the central planning and control system, in harmony with the decentralized planning and control systems.

Implementation

In this section, we give directions for the implementation of the framework. As argued in the introduction of this paper, the framework can support an agile manufacturing strategy only if the organization supports innovation and time compression. In this section we describe transition phases of a traditional hierarchical organization towards a modern innovative product-oriented organization structure.

In traditional hierarchical organizations a top down hierarchy of decision making exists; Figure 2, for example, displays a typical hierarchical structure of a manufacturing company.

Take in Figure 2

To illustrate how disturbances are handled in such an organization, suppose now that there is a disturbance in the production stage, say, a metal cutting machine breaks down. The operator must then inform his supervisor, who in turn informs the manufacturing manager. Since the problem is of a technical nature, he consults the manager of the engineering department. This manager will order the Manufacturing Technology department supervisor to make a manufacturing engineer available to resolve the problem. The engineer will take a look at the problem and perhaps discover a much more serious problem than initially foreseen. It then becomes clear that this machine breakdown strongly corrupts the production plan made by the logistics department, and the engineer will notify his superior. In a similar way, this information is passed on through the various echelons to the planning department. A new detailed manufacturing plan will be made both for the production and the assembly department. To handle the problem, many people and departments were involved and it took a lot of time.

We postulate that our discrete parts manufacturing planning and control framework works best in a *modified hierarchical organization structure*, of which Figure 3 shows a diagram. In such a structure, there is as little hierarchy as possible, with the manufacturing stages at the same level of the hierarchy, a single *Structural Supporting Group* (SSG), and an *Operational Supporting Group* (OSG) for each manufacturing stage.

Multi-disciplinary teams, with members of the SSG, OSG en shop floor employees, are responsible for the overall coordination of specific customer orders. Along with the IMS-structure, the use of these multi-disciplinary teams indicates horizontal coordination, which result in some sort of matrix-organization structure. *Horizontal* coordination refers to the coordination between the different stages of the primary process.

The role of the SSG is to support strategic and tactical improvements of manufacturing systems and processes, such as time reduction with Business Process Re-engineering (BPR) programs. In addition, using the central planning and control system and the Information Management System, it negotiates long-term contracts with suppliers and customers, evaluates long-term capacity plans and large capital investments.

Take in Figure 3

Each OSG is a multi-disciplinary group, closely related to the manufacturing stage it belongs to, which is immediately called upon when an operational disturbance occurs. The task of the OSG is to support the operational running and continuous improvement of current manufacturing systems. Each OSG makes use of the decentralized planning and control system of its corresponding manufacturing stage. The Information Management System provides all planning and control systems in the framework , and hence all SSG and the OSG, with the data and feedback.

Take in Figure 4

It cannot be expected that there are no communication barriers at all in such a modified hierarchical organization. A further flattened, product-oriented manufacturing organization, such as shown in Figure 4, will achieve this better. However, it is seldom the case that a product-oriented discrete parts manufacturing organization is economically feasible.

Conclusions and further research

Although agile manufacturing has been recognized as a major strategy to survive in today's competitive marketplace, there is no suitable manufacturing planning and control framework that truly enables this strategy. To fill this void, we have presented a new, *decentralized* manufacturing planning and control framework for agile discrete parts manufacturing, which is furthermore logistics and business oriented. We have also pointed out how to transform a traditional hierarchical organization into a agile product-oriented organization by implementing multi-disciplinary teams, whose task it is to manage customer orders across the different manufacturing stages, and so-called structural and operational supporting groups. In such an organization, the framework empowers people to resolve problems when and where they occur, in a timely fashion and furthermore enables fast and smooth communication between the different manufacturing stages, multi-disciplinary teams, and supporting groups.

Finally, note that we have only described *what* the different systems and modules are supposed to do. *How* they are supposed to do it, is the challenging topic of our current research.

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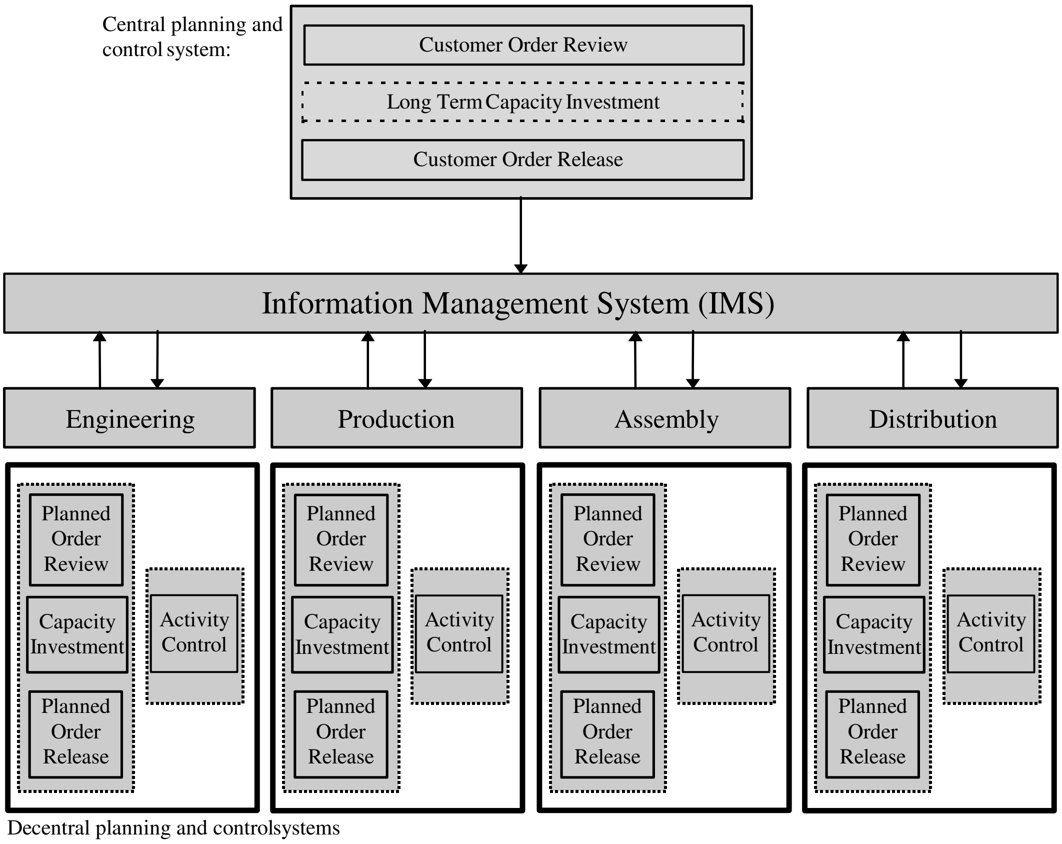

Figure 1: Generic framework for discrete parts manufacturing planning and control.

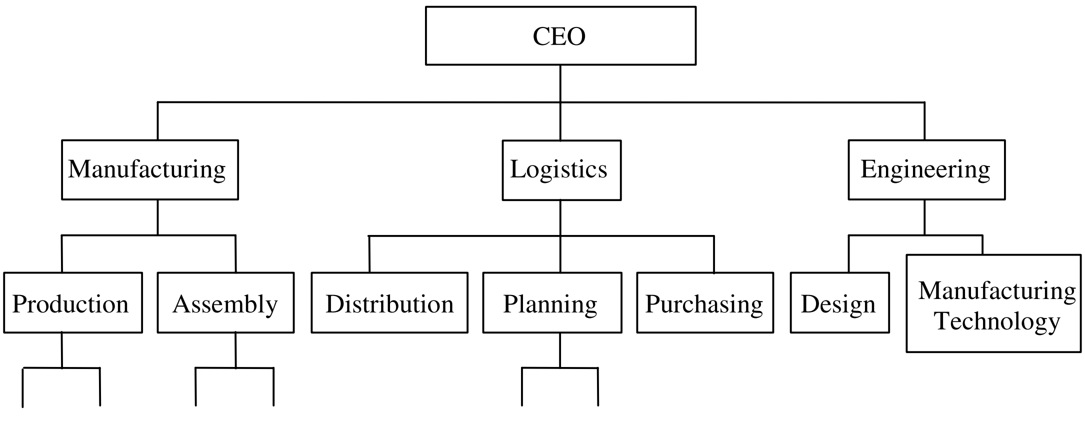

Figure 2: Traditional hierarchical organization structure.

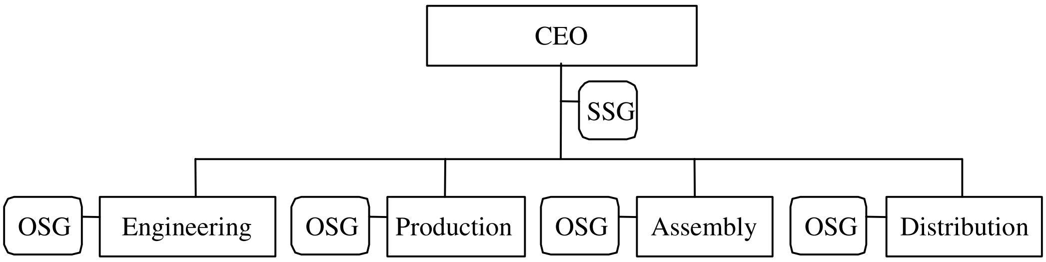

Figure 3: Modified hierarchical organization structure with traditional departments.

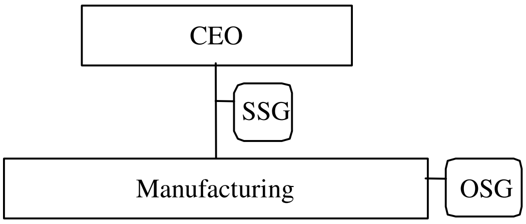

Figure 4: Product-oriented modified hierarchical organization structure.