# Introducing Buffer Management in a Manufacturing Planning and Control Framework

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**Abstract.** Buffer management is not of a great concern when there is a perfect match between demand and supply. Demand represents the requirement for resources, and supply represents the collective capability of the resources to fulfill the requirements. A perfect match would then represent that supply can fulfill demand without any buffers involved, such as materials prepared in advance or capacity not being fully loaded. Such a perfect match is usually not possible to achieve since demand is frequently difficult to predict and the agility of the supply is limited. As a consequence, supply cannot perfectly match demand which may result in insufficient delivery performance. Different types of buffers may be employed to improve performance but they should only be used when the contribution of a buffer is greater than the cost of it. Hence, management of buffers is an important part of manufacturing planning and control (MPC) in order to mitigate such imbalances in pursuit of a competitive supply. The purpose here is therefore to define a framework for MPC that reflects the significance of buffers. To actually establish competitive supply is a complex challenge and four management perspectives are identified to support the balancing of supply with demand. Buffer management is here defined based on the intersection of these four management perspectives related to the transformation flow: the resources employed in the flow, the risk involved in the flow, the decision making related to the flow, and finally the planning and control to balance the flow.

**Keywords:** Manufacturing planning and control • Balance management • Resource management • Risk Management • Hierarchical management

## 1 Introduction

Manufacturing planning and control (MPC) has developed from relying on completely manual routines to integrated computer support in terms of e.g. advanced planning and scheduling systems [1]. Independent of the level of computer support there are some fundamental logics that should be recognized. A key component in this context is that demand defines the requirements and supply employs resources to fulfil that demand. This is also referred to as the mutual relationship between availability of resources and

adfa, p. 1, 2011.

the fulfilment lead-time when supply is responding to demand. A significant part of a lead-time is the queue time which is heavily influenced by the utilization rate. It basically means that if the utilization rate is high (i.e., most of the capacity is loaded) the queue time is extensive and correspondingly if the utilization rate is low the queue time is negligible [2]. This relation is based on the impact on lead-time by uncertainties and indicates that buffers must be carefully located both in terms of capacity, to obtain an appropriate utilization rate, and in terms of materials, to reduce the risk of resources being starved or blocked due to imbalances in the material flow [3]. Even without consideration of uncertainty there may be deviations between demand and supply. A typical example is the financial evaluation of ordering costs resulting in economic order quantities where level demand is balanced with lumpy replenishment of an inventory buffer. This could also be exemplified by seasonal demand for stocked items and level supply where seasonal inventory works as a buffer. Depending on the situation it might also be necessary to have capacity buffers. Buffers are therefore an important component for balance management but due to costs a buffer is always limited and with limited buffers a system is exposed to variability and the delivery capability may be compromised. As a consequence, the location and dimensioning of buffers is a key challenge for MPC and understanding how to use resources to establish buffers is an important capability.

The two categories of resources (i.e., materials and capacity) have been highlighted in the MPC literature since the inception of the research area. To have enough materials and capacity is a key challenge and in combination they provide great complexity. Therefore, they are traditionally handled in sequence where one is managed before the other. In MRPII for example the first focus is on balancing materials and thereafter the capacity balancing between required and available capacity is performed. In some process industries the approach is reverse where key resources are loaded and then the resulting inventory levels are checked. In either case, the expected plan is determined using the appropriate buffers to handle different types of variability. In some cases, the buffers are estimated based on formal procedures and updated periodically but usually they are handled in a more informal way far from the statistical methods of inventory control.

The purpose of this research is therefore to outline a refined framework for MPC that explicitly highlights the significance of imbalances between demand and supply and the consequent requirements for buffers. Next, balance management, resource management and risk management are outlined followed by introduction of hierarchical management. Thereafter, the conceptual framework for MPC is introduced where the sixteen components of buffer management are defined and the design of units of analysis is outlined. Finally, some concluding remarks and implications of the framework are indicated.

## 2 Frame of reference

MPC is fundamental for the business to be profitable and to provide a competitive return on investment. At the core of this challenge is supply in response to demand with the purpose of striking a competitive balance between efficiency and responsiveness [4]. This balancing act is based on resource management covering all the available resources. In an MPC context, the resources are usually divided into the objects being transformed (i.e., materials) and the objects actually performing the transformation (i.e., transformands). In particular, the capacity of the transformands are then emphasized and hence resource management is performed in terms of materials and capacity. Balancing is exposed to uncertainty in supply as well as in demand and this is covered by risk management. Risk is a general concept but traditionally risk in MPC has been associated with some measure of uncertainty and the most common is the standard deviation [5]. When the uncertainty is identified the remainder is the expected outcome, the target for regular MPC. Finally, decision making in MPC is complex and covers long term strategic decisions involving positioning of the business in relation to the context of different markets where suppliers and customers meet, as well as short term execution challenges. To manage this type of complexity a hierarchical approach has evolved that is case specific. Still some general guidelines for hierarchical management can be identified. In total this means that four management perspectives of MPC are identified and constitute the foundation for buffer management in this research:

- Balance management: Demand and Supply
- Resource management: Materials and Capacity
- Risk management: Regular and Safety
- Hierarchical management: Structural, Aggregate, Detailed and Execution

### 2.1 Balance management: Demand and Supply

The fundamental principle of logistics in any setting is the balancing of demand and supply. Demand can originate from external customer requirements as well as internal requirements related to internal customers such as a stock point that needs to be replenished. External demand can either be a projection of future requirements in terms of a forecast or based on actual customer orders. Also, internal demand can be based on expected future requirements or actual requirements. Demand may therefore be considered as certain or uncertain. Supply represent all the activities related to fulfilling these requirements. In the same vein as demand, supply may be uncertain or certain in terms of both volumes and timing. Consequently, balancing is challenging due to the combination of certain and uncertain variations in demand and supply. Buffers are used to mitigate the imbalances between demand and supply. A buffer is thus a key element in balance management and the challenges of positioning and dimensioning buffers is here referred to as buffer management. A buffer basically enables decoupling of supply from perfect tracking of demand. In summary, the two types of balancing can be categorized as either being performed at a “macro” level related to external customers or at a “micro” level related to internal customers and in both cases buffer is a key mechanism for mitigating imbalances.

## 2.2 Resource management: Materials and Capacity

Resource management is complex since it involves the timing of numerous transformations being performed by a wide range of transforming resources. To simplify matters the objects being transformed are managed separate from objects performing the transformation. The objects being transformed are here referred to as materials and consequently the management of these resources is referred to as materials management (MM). One unique characteristic of materials is that when produced materials is not utilized immediately, it can be inventoried for later use. In some cases, there are some further constraints related to for example perishability, that further complicates MM.

The transformation of an object requires transforming objects. These transforming objects are here referred to in term of their capacity, and the management of these resources is referred to as capacity management (CM). When there is a mismatch between demand and supply there is a need to either adjust supply or demand, where adjustment of supply is primarily by making changes in capacity. The resources that typically are used to adjust the capacity level in the long or short term are buy/sell capacity, personnel, and machines each with their unique properties in terms of flexibility. High flexibility also correlates with higher capability level and can be achieved by flexible machinery, cross-trained employees and quick changeovers. In contrast to materials, capacity cannot be saved from one point in time to later since an hour lost is an hour lost forever.

## 2.3 Risk management: Regular and Safety

Borrowing from the language of quality management and forecasting the concept of regular is associated with systematic variations (i.e., expected events) and safety associated with stochastic variations (i.e., unexpected events, uncertainty). Risk management is a quite general challenge but as outlined above it can be identified as identifying and managing uncertainty in the system. Aspects not involving any uncertainty are referred to as regular and can be symbolized by the Greek letter mu ($\mu$), which in statistics is associated with the expected outcome. In terms of a material requirements planning (MRP) system the regular part would concern the net planning mechanism and the fundamental principles for generating the planned orders. The safety part can be symbolized by the Greek letter sigma ($\sigma$) and is represented by for example safety stocks or safety lead-times that are added to the generation of planned orders. In general, two different types of uncertainties can be identified; uncertainties in demand and uncertainties in supply. When and how much a resource is needed is based on uncertainties in demand, while questions about a resource and its availability is based on uncertainties in supply. The uncertainties vary to some extent depending on the types of resources concerned. For materials, an uncertainty buffer can be in the form of a safety stock of materials and for capacity it can be safety capacity, both referring to some additional amount compared to the regular level required to meet occasionally higher demand. Capacity can refer to resources in terms of machinery as well as personnel. In addition, safety buffers can be placed in different parts of the value flow based on their purpose.

### 2.4 Hierarchical management: Structural, Aggregate, Detailed and Execution

A monolithic approach to MPC is extremely challenging since the amount of information available is overwhelming and in addition different types of decision concern different time horizons. When performing strategic positioning of the company information about the queue in front of an individual machine provides limited value. Instead the information of value to each individual balancing decision should be identified and both resource management and risk management have unique characteristics for different time horizons. The long-term decisions concern the positioning of the company network of sites in relation to markets and are considered as part of the operations strategy. This strategic positioning is here referred to as the Structural level (StL) and fundamental for multi-site scenarios and supply chain design. Once the positioning is performed the next logical issue to manage is dimensioning of resources at each node of the network, often seen as tactical demand and supply balancing. Some decisions related to dimensioning are made at StL but other aspects are still possible to adjust such as personnel, contracts with suppliers, machine utilization, seasonal inventory or backlog . This type of planning is usually performed at the Aggregate level (AgL) under the heading of sales and operations planning (S&OP). Once dimensioning is performed the actual volumes possible to produce are set and focus shifts to the mix of the output. In most cases the mix is considered at the independent level (master scheduling) and the dependent level (materials planning) but in general this planning issue concerns the coordination of resources at an item level and in some cases at an operation level. This level concerns detailed planning and scheduling of materials as well as capacity with the objective of fulfilling customer orders and is therefore referred to as the Detailed level (DeL). Once the detailed planning and scheduling is performed the last step with the shortest time-horizon is the actual execution of the plan, at the Execution level (ExL). In summary, hierarchical planning is split into four distinct levels based on the type of decisions to be made, the details of the information considered and on the time-horizon employed. From longest to shortest time-horizon these are: Structural level, Aggregate level, Detailed level and Execution level.

## 3 Framework for manufacturing planning and control

The four management perspectives outlined above is each important for MPC. It is however in combination that their significance for buffer management unfolds and provides support for positioning problems. By combining the four management perspectives it is possible to identify sixteen components for buffer management. These components can be combined in terms of different unit of analysis for buffer management.

### 3.1 The sixteen components of buffer management

The sixteen components are identified through logical deduction using a combinatorial approach. By combining resource management (materials and capacity) with risk management (regular and safety) it is possible to identify four combinations between these concepts. The identified combinations are materials-regular, materials-safety, capacity-regular and capacity-safety. Since risk management is significant in both MM and CM, safety management is highlighted in relation to regular management and the identified combinations is thus referred to as Safety Materials Management (SaMM), Regular Materials Management (ReMM), Regular Capacity Management (ReCM), and Safety Capacity Management (SaCM) as shown in Fig. 1

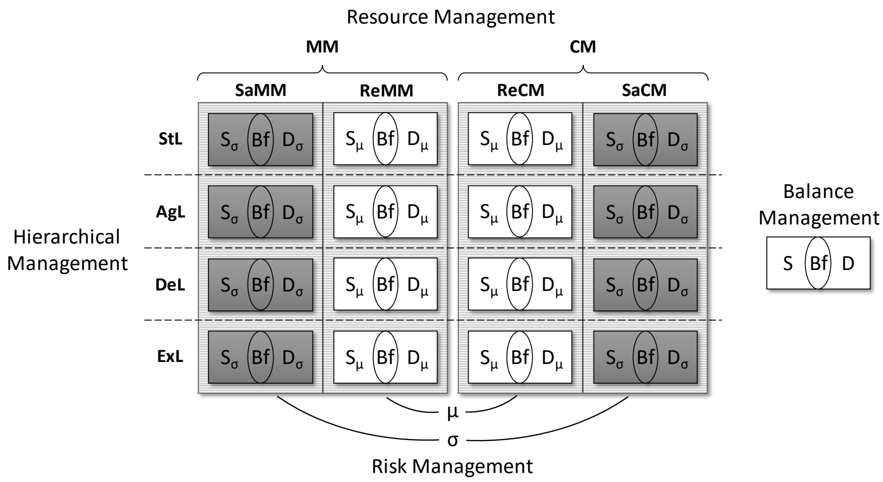


**Fig. 1.** MPC framework combining resource management, risk management, hierarchical management and balance management

As mentioned above, "regular" represents expected events and probable outcome of demand and supply in MPC, thus considering systematic variations but ignoring uncertainty. Regular involves much of the fundamental planning principles. Dimensioning in ReMM concerns for example buffers in terms of cycle stock with the counterpart of ReCM which then would concern cycle capacity. The opposite of regular is irregular, which represent uncertainties (stochastic variations) that are handled with safety buffers. Safety buffers should also be based on expected values with the difference that buffers are a matter of expected properties of fluctuations. SaMM includes, for example, dimensioning of safety stocks based on the planning levels' requirements. In analogy with material buffers, the capacity buffers can be highlighted in a similar manner as for materials, which here is represented by SaCM.

In total MM and CM can, as indicated above, be divided into four management approaches (ReMM, SaMM, ReCM and SaCM) and by also including hierarchical management levels the framework of Fig. 1 is derived. By combining the four types of regular and safety management with four levels of hierarchical management it is possible to identify the sixteen supply-demand balancing elements represented by S, D and Bf (Buffer) in Fig. 1. For each element, that represents a unique supply-demand balancing task, the subscript μ is used for regular and σ for safety.

### 3.2 Unit of analysis for buffer management

Buffer management takes care of the imbalances between demand and supply. The components identified in Fig. 1 constitutes the components of scenarios for buffer management in the sense that a unit of analysis includes a set of components. A unit of analysis is therefore here defined as a set of components. For example, buffer management related to AgL, in a S&OP process, would cover all four components of AgL including the intersection between AgL and SaMM, ReMM, ReCM and SaCM. Each component presents specific balancing challenges for mitigating the imbalances between demand and supply. A different unit of analysis would be to for example only focus on uncertainty based buffers, i.e. safety buffers at specific hierarchical levels. The framework explicitly highlights the need of covering uncertainties in MPC by including buffer management in terms of SaMM and SaCM. The distinction between regular and safety is often implicit in the literature on MM, while it traditionally is hardly present in the literature related to CM (see e.g. [2]). Uncertainties are often included in MM (e.g., safety stock calculations) but are usually not visually illustrated separate from their use in SaMM. In the context of capacity, risk management is managed as a whole without this distinction. There are several methods for capacity planning, utilization and making capacity changes, which all relate to ReCM. Although, methods and techniques for the actual dimensioning of safety capacity have not been clearly indicated in the literature. In this sense, SaCM is an extension of a traditional view of MPC. Even though SaCM has not been much highlighted in the literature it still exists in practice, although it is mostly based on experience rather than on formal methods. The characteristics of SaCM in practice was indicated in a case study conducted 2016 [6], where several case companies used safety capacity buffers to handle unexpected events. One of the companies' targeted 20% extra capacity in relation to regular capacity requirements in order to supply potential new market demand, that however might never occur. This type of dimensioning is in particular associated with AgL but based on explanations from the case companies it actually spans over several additional hierarchical levels to different degrees and is considered to be of different character based on the planning levels. When referring to dimensioning of different degrees it primarily indicates that the ability to make changes at lower planning levels are constrained by higher level decisions, since higher level decisions set the boundaries for the next lower planning level. As mentioned above, a safety buffer provides a margin to protect against uncertainties such as random variations in demand and is important to consider in order to be competitive. Thus, the proposed framework distinguishes between regular and safety to illustrate the two fundamental parts of buffer management in terms of MM and CM. Subsequently, it also highlights SaMM as a separate part of MM instead of being implicit and adding SaCM as part of CM, which in turn leads to an indication of a knowledge gap about SaCM.

## 4 Concluding remarks

Buffer management has traditionally not been a clearly elaborated part of MPC. In particular, the dimensioning of resource buffers has been implicit in MM and CM with limited support on how to determine the buffer sizes. A distinction is made in this research between regular and safety. Note that the framework indicates different types of buffers and it can be used for design of MPC but also be used to indicate how to perform the actual operation of MPC. The difference can be explained for MM in terms of MRP and safety stocks, where the use of a buffer such as a safety stock in MRP would be in ReMM since the operation is completely based on expected outcome. The decision about the size of the safety stock SS would however be covered by SaMM as a design issue. When it comes to CM, SaCM has been identified in practice as important for competitiveness but actual decisions regarding the buffer size is mostly based on intuition since the availability of formal methods for this purpose is limited. In this context capacity requirements planning (CRP) would use for example utilization rate in operation as an indication of required buffer capacity in ReCM but the actual estimation of the utilization rate would be covered by SaCM as a design issue. In addition, buffers are needed on all planning levels but the question is how to determine the buffer size and where to position them. Hence, decisions regarding the buffers at different hierarchical levels could be elucidated further in the areas of SaCM to complement SaMM.

This research provides a complement to the traditional view by a refined framework for MPC that highlight the significance of buffer dimensioning, see Fig. 1. The framework identifies sixteen different components for buffer management. The components constitute building blocks for a buffer management unit of analysis defined for a particular case. The MPC framework could be generalized to an operations planning and control (OP&C) framework by also considering services. The framework offers several paths for further research but the SaCM part of the framework lacks formal support and is of particular interest to gain further insights on from both a theoretical and empirical perspective.

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## References

1. Stadtler, H., Kilger, C., Meyr, H.: Supply Chain Management and Advanced Planning Concepts, Models, Software, and Case Studies. Springer Heidelberg, Berlin (2015)
2. Blackstone, J.H.: Capacity management. Thomson South-Western, USA (1989)
3. Goldratt, E.M., Fox, R.E.: The Race. The North River Press, USA (1986)
4. Chopra, S., Meindl, P.: Supply Chain Management: strategy, planning, and operation, vol. 6. Pearson, Boston (2016)
5. Silver, E.A., Pyke, D.F., Peterson, R.: Inventory management and productions planning and scheduling. Wiley, New York (1998)
6. Hedvall, L., Sollander, K.: Capacity dimensioning of operations capacity in manufacturing companies. In. Jönköping University, Jönköping, (2016)