Modelling and optimization of a machine production process: Buffer stock supply implementation and replenishment control

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Abstract. In the industry and logistic the production process is the sequence that aims to convert raw materials into finished or semi-finished products. It is identified as one of the most complex phases of the supply chain due to its close interdependence with other processes such as replenishment. In this perspective, the efficiency of the manufacturing process essentially relies on the decisions of the responsible operators for supplying machines with raw materials. These decisions do not ensure optimal operation efficiency. This document proposes a scientific study based on the modelling and control of the production process in a smart industry perspective. Initially, one will present a modelling of the manufacturing system conceptualized as an industrial machine, as well as the replenishment policy, that will be conceived as a control loop tuning the raw material supplies quantities into the production machine following a proposed architecture.
We will then proceed to simulate this scenario using the Simulink interface to identify the most influential parameters and improve them.
Keywords – Smart manufacturing system, Production machine, Replenishment, smart control, Simulation, Stock Regulation.

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1 Introduction

2 Main Concepts

2.1 Production as an interdependent system

The systemic approach to industrial production constitutes a conceptual perspective for understanding all components and interactions within a production system. This approach transcends the simple sum of parts to consider production as an interconnected system, where each element plays a crucial role in the whole. By adopting this vision, we recognize that production processes, replenishment operations, and other operational aspects cannot be understood in isolation but must be evaluated within their interdependent context. The interrelationships between these components manifest not only in logistical terms but also in reciprocal influence on product quality, costs, and ultimately, the overall performance of the industrial entity [8].

2.2 Replenishment operations within an internal production system

In the context of production and warehousing, replenishment plays a vital role in ensuring the flow of materials and products throughout the supply chain [1]. Given that production systems heavily rely on timely access to raw materials and components, replenishment becomes a critical link in the chain. After the order-picking process, where goods are retrieved to fulfill specific customer orders, it's imperative to replenish the utilized inventory to maintain adequate stock levels for ongoing and future production cycles [4]. In our specific case, replenishment is an internal operation that ensures a steady supply of materials to support manufacturing operations. Proactive control of replenishment processes is a critical factor that can significantly enhance the performance of production operations. By ensuring that materials and resources are consistently available at the right time and in the right quantities, well-regulated replenishment can minimize production delays, reduce inventory costs, and improve workflow continuity [3-4].

2.3 Buffer stock

Buffer stock, also referred to as intermediary stock, is generally a small inventory positioned directly for use by production machines. This stock is replenished by the internal warehouse, with production machines drawing materials directly from the buffer stock. To maintain optimal machine performance, it is essential to continually regulate the buffer stock based on real-time machine consumption and replenishment rates from the internal warehouse.

2.4 Manufacturing process architecture

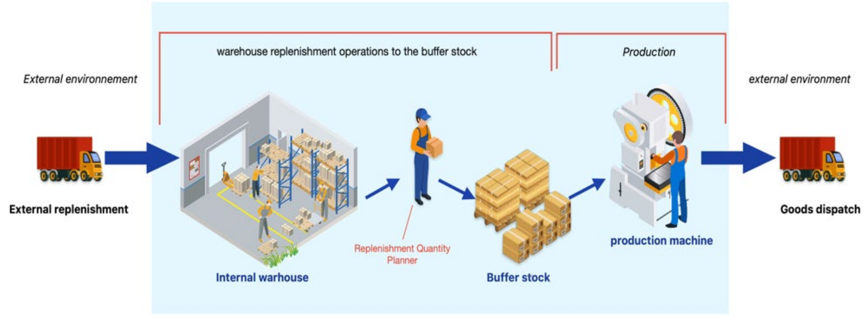


Fig. 1. Manufacturing process within a factory

This production mechanism involves a series of sub-processes that collectively bring a final product to fruition. Three critical stages stand out in the production chain: the replenishment of raw materials from the warehouse to the buffer stock, the transfer of these materials from the buffer stock to the machinery, and the actual production operation.

Exploring these sub-processes will enable a detailed analytical and scientific understanding of their dynamics, ultimately leading to the optimization of the entire manufacturing workflow.

3 Modelling the buffer stock and the replenishment policy

3.1 Buffer stock representations

This buffer stock system consists of three main components: the buffer stock itself, the production machine, and the replenishment operation that transfers materials from the warehouse to the buffer stock.

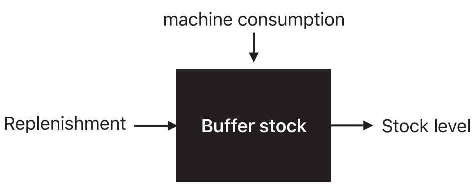


Fig. 2. Black box representation of the buffer stock

The production machine, as the primary consumer of materials, interacts with the buffer stock to ensure a continuous flow of resources that sustains uninterrupted production and adapts to shifting demand dynamics. Complementing this, the replenishment operation orchestrates material transfers from the warehouse to the buffer stock. To control this process, the proposed solution involves the implementation of an automated system that ensures the buffer stock remains at an optimal level, while the production machine continues to consume materials from the buffer stock.

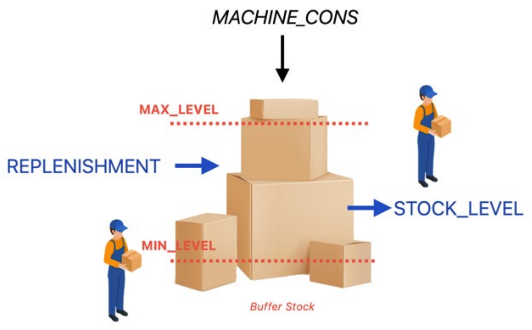


Fig. 3. Representation of the buffer stock parameters, input and output

In our modeling approach using Simulink, we designed the buffer stock as a dynamic function characterized by both an inflow and an outflow. The inflow represents the replenishment from the warehouse, while the outflow corresponds to the consumption rate of the production machine. This sub-system was modeled using a sum block to subtract the outflow (consumption) from the inflow (replenishment), followed by an integrator to accumulate the resulting quantity over time. The integrator's output represents the current level of the buffer stock. Additionally, we incorporated reference variables to define the buffer stock's maximum level (MAX_LEVEL) and minimum level (MIN_LEVEL).

3.2 Implementation of hypothesis

In this section, we will implement several hypotheses to simplify the simulation model and focus on the core dynamics of buffer stock and production machine interactions. These hypotheses will help isolate specific variables and provide a clear understanding of the fundamental processes.

3.2.1 unlimited warehouse capacity

Our first hypothesis assumes that the capacity of the warehouse stock is unlimited. This means that replenishments are always available whenever needed, eliminating any constraints on material availability. This assumption allows us to focus on the dynamics between the buffer stock and the production machine without considering supply shortages or stockouts at the warehouse level.

3.2.2 Neglecting replenishment delays

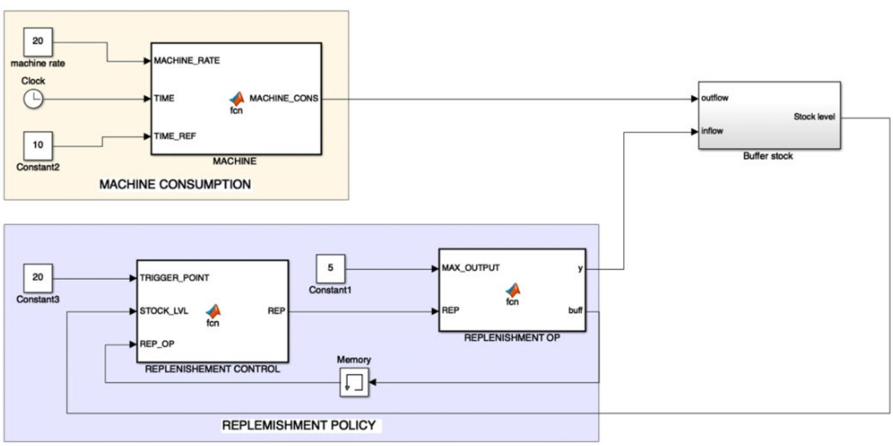
The second hypothesis involves neglecting the delays associated with the replenishment process from the warehouse to the buffer stock. In real-world scenarios, these delays often arise from operator handling, transportation, and other logistical factors. However, for this initial model, we will assume that replenishments occur instantaneously once the buffer stock level reaches the minimum threshold. This no-delay assumption creates an ideal scenario, allowing us to understand the system's behavior and the impact of replenishment policies without the added complexity of time lags.

3.2.3 Fixed production rate and push flow

The third hypothesis posits that the production machine operates at a fixed production rate and follows a push flow production model. This means that the machine consistently consumes materials from the buffer stock at a constant rate, regardless of downstream demand or inventory levels. This fixed consumption rate is a simplification that allows us to analyze the steady-state behavior of the buffer stock without fluctuations in demand.

3.3 Modelling of the buffer stock system & Replenishment loop control

This SIMULINK model is composed by 3 areas: the machine consumption, the buffer stock and the replenishment policy as follow.



. **Fig. 4.** Block diagram modelling of the buffer stock regulation loop in Simulink

- MIN_LEVEL: minimum capacity of the buffer stock also used as a trigger point (TRIGGER_POINT)
- STOCK_LVL: real time quantity in the buffer stock
- MACHINE_CONS: consumption rate of materials by the production machine.
- MACHINE_RATE: machine production rate quantities (known parameter)
- MAX_OUTPUT: maximum quantity that that one operator can supply

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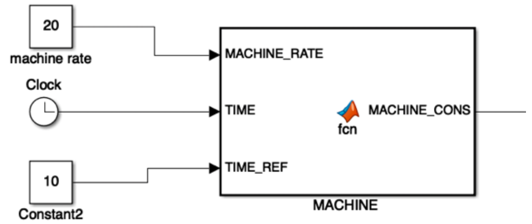
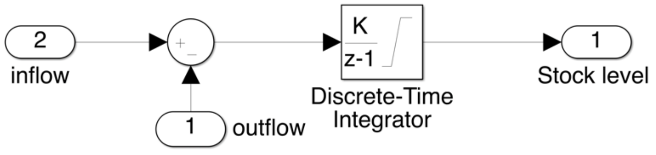


. **Fig. 5.** Machine consumption Block in Simulink

The machine consumption block operates following the script:

```
function MACHINE_CONS = fcn(MACHINE_RATE, TIME, TIME_REF)
if mod (TIME, TIME_REF) == 0
   MACHINE_CONS =MACHINE_RATE;
else
 MACHINE_CONS = 0;
End
```

This MATLAB function block in Simulink models machine consumption based on parameters MACHINE_RATE, TIME, and TIME_REF. It evaluates if the current simulation time TIME aligns with intervals defined by TIME_REF. When true, MACHINE_RATE is calculated as 20% of the buffer stock level and is assigns MACHINE_CONS to MACHINE_RATE, indicating active consumption at that time step. Otherwise, it sets MACHINE_CONS to zero, implying no consumption.



. **Fig. 6.** Buffer stock subprocess model

The buffer stock is represented as a subprocess with two primary inputs: the outflow, corresponding to the machine's consumption rate, and the replenishment input from the warehouse. The output of this subprocess is the buffer stock level (STOCK_LEVEL). The modeling approach uses a sum block to subtract the outflow (from the machine consumption block) from the inflow (from the replenishment control block). This difference is then fed into an integrator block, which accumulates the net flow over time, representing the current capacity of the buffer stock. This setup allows us to dynamically

simulate changes in buffer stock levels based on the rates of consumption and replenishment.

The system (. **Fig. 4.**) in controlled by two other Simulink blocks, REPLENISHEMENT CONTROL and REPLENISHEMENT OP that constitutes the replenishment policy. The feedback loop operates as follows: When the buffer stock level falls below a predefined minimum threshold (STOCK_LEVEL <= TRIGGER_POINT), the replenishment order is triggered. The replenishment quantity is determined by a MATLAB script:

```
function REP = fcn(TRIGGER_POINT, STOCK_LVL, REP_OP)
  TMP = 0;
  if (STOCK_LVL <= TRIGGER_POINT) && REP_OP == 0
    TMP = 80;
  end
  REP = TMP;
end
```

As the replenishment quantity is 80 % of the buffer stock capacity, we managed to integrate a manual replenishment according to a real manufacturing scenario which is the REPLENISHEMENT OP block following the MATLAB script :

```
function [y , buff] = fcn(MAX_OUTPUT, REP)
  persistent REP_OP;
  max = MAX_OUTPUT;
  if isempty(REP_OP)


    REP_OP = 0;
  end
  REP_OP = REP_OP + REP;
  if REP_OP >= max
    y = max;
    REP_OP = REP_OP - max;
  else
    y = REP_OP;
  end
  buff = REP_OP;
end
```

MAX_OUTPUT represents the maximum amount the operator can hold. The function accumulates replenishment quantities (REP) in REP_OP and checks if it meets or exceeds MAX_OUTPUT. If so, it replenishes MAX_OUTPUT and adjusts REP_OP accordingly. If not enough is available, it replenishes what is in REP_OP. The output 'y' shows the actual replenished amount, and 'buff' tracks the remaining replenishment needs for future cycles.

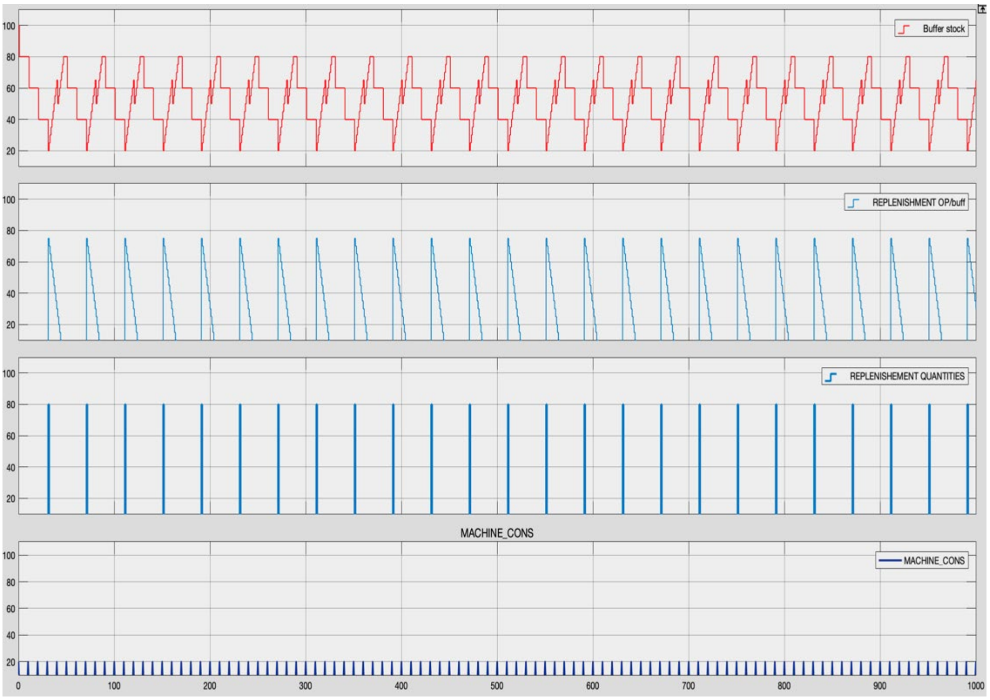
Once replenished, the buffer stock is again available for the production machine's consumption. This continuous feedback creates a control loop that ensures the buffer stock maintains optimal levels, preventing stockouts and production delays.

Within this system, the machine's material consumption is viewed as a perturbation, and our model emphasizes the modeling of buffer stock and the implementation of replenishment control mechanisms to regulate buffer stock levels.

4 Simulation and Analysis

In the simulation of this specific production scenario using Simulink, we highlighted the interactions between the buffer stock levels, the machine's consumption, and the replenishment quantities and operations. These elements were visualized through the Scope block in Simulink, which shows how these variables change over time in relation to the simulation clock.

In our model, the machine's consumption was set at a fixed rate to meet demand. This consumption rate represents the quantity of materials the machine uses over a given period, ensuring continuous production to satisfy market requirements.



. **Fig. 7.** Buffer stock, Replenishments, machine consumption simulation cycles in Simulink

The machine's consumption rate was fixed at a constant value of 20% of the buffer stock capacity per time interval. This constant consumption rate simplifies the analysis by providing a steady, predictable demand on the buffer stock.

The simulation results illustrated the dynamic interplay between these factors. As the buffer stock level decreased due to the machine's consistent consumption, the replenishment process was triggered whenever the stock level fell to the trigger point set at 20% of the buffer stock level. This threshold-based trigger ensured that the buffer stock was replenished, preventing it from depleting completely and avoiding potential disruptions in the production process.

The replenishment quantities and operations (the second and third layouts of the simulation scope) followed the MATLAB script mentioned earlier. We can clearly observe that the replenishment operations decrease by a step of 5%, which is the maximum quantity that an operator can hold and supply. Following the control policy, the buffer stock was restored to an optimal level sufficient to meet the ongoing demands of the production machine.

We also observed that the stock level fluctuated within the defined bounds, demonstrating the system's ability to maintain an adequate buffer. The replenishment quantities varied as needed to keep the stock level between the minimum and maximum thresholds, reflecting a responsive replenishment policy.

5 Conclusion and research perspectives

The production process, characterized as a sequence of organized operations aimed at transforming raw materials into finished or semi-finished products, is closely interdependent with other supply chain processes, particularly replenishment. In response, we proposed a scientific study focused on the modeling and control of the production process. Initially, our attention lies in conceptualizing the manufacturing system as an industrial machine and delineating a replenishment policy structured as an automated loop that orchestrates raw material supplies to the production machine within a proposed architecture. Through this approach, we aim to optimize manufacturing mechanisms by integrating automation as a tool for modeling and simulation, fostering a deeper understanding of production dynamics.

This simulation has laid the groundwork for future research, recognizing the importance of incorporating real-world complexities such as operational delays, interactions among multiple machines and smart technology. Our work introduces the essential parameters necessary for developing more sophisticated and accurate models of production systems, emphasizing the need for realism in our simulations. This understanding of production environments and the factors influencing their dynamics allows us to refine our models to better capture the complexities involved.

Our work represents a foundational step in simulating a production scenario, focusing on a straightforward case to pave the way for more complex simulations. This initial approach enabled us to model and understand the dynamics of buffer stock management and replenishment in a controlled environment.

In this specific case, several simplifying assumptions were made. Notably, we neglected operational delays in the replenishment process, considering it an ideal scenario without delays. This assumption does not align with real-world production settings, where delays add complexity and variability due to factors such as operator handling and logistical constraints. Our next steps will address these limitations by incorporating delays into our model.

We plan to utilize the modeling approach proposed by J. Wikner, which involves a generic delay model in continuous time characterized by two fundamental parameters: T (time constant) and n (order of the event). This approach will help us develop a more realistic simulation that includes delays in production processes.

The identification of parameters, such as buffer stock levels and machine consumption rates, now serves as a fundamental basis for developing production scenario simulations to achieve a more accurate representation of real-world conditions, ultimately leading to more effective optimization strategies.

Our approach demonstrates a clear improvement in maintaining continuous production flow compared to fixed replenishment models. While advanced systems like IoT-enabled control offer the potential for even greater efficiency, this research provides a foundational step toward integrating such technologies into industrial logistics. Recent studies, such as Chen et al. (2023), which utilize predictive and real-time methodologies, reveals that our approach emphasizes greater flexibility and practical application in dynamic, evolving industrial environments. These comparisons highlight that the current model prioritizes simplicity and adaptability, with room to evolve into more complex systems aligned with advanced methodologies seen in recent literature. By focusing on a scalable and adaptable framework, this work lays the groundwork for future developments that can progressively incorporate cutting-edge technologies, ultimately enhancing the overall efficiency of industrial supply chains.

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