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Modelling sources of operational noise in production systems

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Abstract

This paper aims to identify and model the sources of operational noise that contribute to unstable and poor flow of materials in production systems. 80 interviews with managers and decision-makers were conducted and analyzed and have revealed that internal technical instabilities, employee variability, and customer and supplier uncertainty are the major sources of operational noise. They have also identified the relationships between the different variables of a production system that contribute to the amplification of operational noise and hence should be managed effectively to ensure a smooth flow in manufacturing operations.

Keywords: Flow; Manufacturing; Production Systems; Operational Noise; Causal Loop Diagrams

1. Introduction

Flow in manufacturing operations commonly defined as the flow of material and information between suppliers, the organization, and its customers, constitutes one of the most important management task for manufacturing companies and, through its link to cash flow, it is one of the areas of management with the highest impact on business results [1]. Decision-makers in manufacturing organisations have yielded various levels of successes when trying to achieve undisturbed and swift flow [2], even within the same industry sector and market conditions [3]. Operational noise, referring to a multitude of diverse and random process disturbances, is a main reason why manufacturing organisations fail to reach high levels of flow. Operational noise can be defined as “any event, process, or activity that creates excess errors, delays, and/or rework as a result of uncertainties caused by poor information exchange or physical processing” [4]. This paper investigates operational noise as a main contributor to poor performance in manufacturing operations, related to material and information flow. It tries to answer the question: what are the main sources of operational noise that inhibit flow in manufacturing organisations? Using qualitative analysis obtained from interviews with decision-makers in manufacturing organisations, major sources of operational noise are identified. The paper presents some of the major cause-and-effect relationships of noise identified in production systems modelled using Causal Loop Diagram (CLD).

2. Literature review

Flow within a manufacturing organization is made up of tangible flows that produce, convert, and deliver products, and intangible flows that do not directly produce outputs but are still necessary to trigger production, such as information and decisions flows (the domain of feed-forward systems and systems dynamics). The tangible material flow within a manufacturing environment is the movement of materials through a defined process or a value stream within a factory or an industrial unit to produce a finished product [5]. It involves the delivery of products to customers, and, when free from wastes and bottlenecks, the physical flow of materials can

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positively influence performance. The intangible flows of information are essential for managing the overall business operations. They provide a platform for knowledge sharing and facilitate the effectiveness and efficiency of business operations by timely management of the physical flows [6]. Swift and even operations flow of materials [7] from the supplier through the production system towards the customer, plus an undisturbed clear flow of information in the opposite direction have been shown to be the de-facto characteristics of high-performance operations management; a goal long sought by practitioners and academics.

2.1. Operational noise & disturbances to flow

A poorly designed system is a source of uncontrolled variation and delay which only causes operational noise, disturbances, and chaotic conditions [8]. Operational noise and disturbances in a production system are both unexpected and unplanned, leading to a deviation between planned production and the steady-state of the production system [9]. Operational noise is a main cause for poor material flow and therefore needs to be minimized, for the organization to maintain swift and even flow. Operational noise is amplified by [4]:

- Ineffective design decisions that do not support the business in achieving its goals,
- Problems within and loss of productive capacity,
- Problems associated with inbound supply,
- Lack of or inconsistencies in quality and quantity of information exchange.

Operational noises in production systems are typically found in the production capacities, in the various process inputs and the information flows. Depending on how often they occur, operational noises can be divided into chronic and sporadic. Sporadic noises are more obvious as they occur suddenly as significant deviations from the normal behaviour of the system, such as machine breakdowns, unavailability of materials, or operator absenteeism. These disturbances occur irregularly, and their effects are dramatic which often leads to serious problems. On the other hand, chronic noises are usually small and not obvious, they also tend to be complicated because they are the result of several concurrent causes and represent systemic losses of the ideal machine/line capacity. Chronic noises are often mistaken as normal behaviour thus making them more difficult to identify as staff work with typical speeds rather than the designed speed of the asset or line [9].

2.2. Managing operational noise, managing flow

Operations management strategies are influenced by operational noise and therefore are determinants in operational performance. The notion here is a causal relationship between the organisation's strategy and its environment, and that these strategic decisions determine the performance outcomes [10,11]. The strategy used depends on the severity of the noise and the preference of decision-makers [9]. Researchers have highlighted different strategies to manage operational noise, such as the concept of lead time reduction, elimination of wasteful non-value adding activities, and supply chain redesign, collaboration with suppliers and customers, effective information sharing, flexibility across all the supply chain, postponement, and buffering.

Strategies used to manage noise can be either to focus on its reduction or to manage effectively with it or both [12]. By choosing to reduce noise, an organisation would be classed as having a proactive approach towards its environment. On the contrary, an organisation that chooses to cope with the noise would be labelled as having a reactive strategy and can be deemed to be comparatively more 'agile'. Organisations can also use buffering strategies, which are resource-based approaches that require excess materials, machinery, or labour capacity and dampening strategies that are information-based approaches based on planning methodologies [9]. If operational noises are not buffered or dampened completely, they will have negative effects on the output of the system and its customer service. The relationship between operational noise and flow has been studied in different contexts, such as the impact of environmental factors on manufacturing performance [13], the effects of supply and demand uncertainty on supply chain performance [14], the effects of internal and external integration efforts under different environmental conditions [15], and the influence of manufacturing systems' design on dampening operational noise [4]. This confirms the negative effects of uncertainty and operational noise on performance and the need for them to be effectively managed to achieve swift and even flow.

The effects of operational noises can be viewed as disturbances to the production resources or disturbance to the production system inputs and outputs. In that effect, production resources might be affected by disturbances due to breakdown of machines, tools and absence of the workforce, or information systems. Inconsistencies and variation in production speeds and delivery schedules affect the production resources in the form of utilization of machines or availability of materials. The disturbances to production system inputs and outputs are due to delays or incorrect orders and deliveries [9]. Moreover, the poor quality of the inputs or the outputs is a main cause of disturbance to material flows and could therefore affect the core of an organization's competitive advantage.

Table 1. Examples of operational noise effects

Typical effects of operational noises	Examples
Material Shortages	Delays in deliveries and Incorrect materials or components
Breakdowns	Unplanned maintenance, employee absenteeism, and information systems
Reworks	Poor product quality
Non-standard production	Variation in processing time

3. Manufacturing systems' causal loop diagram

Manufacturing systems and their behaviour have been modelled using various modelling approaches [16]. Amongst these are system dynamics Causal Loop Diagram (CLD). Causal Loop Diagrams (CLDs) graphically illustrate causal relationships and major feedback loops among variables of a system. The main goal of these models is to identify all possible interactions among variables and decisions. CLDs map the hypotheses of system structures by linking causal relationships between variables [17]. Developing CLDs involves identifying stakeholders and endogenous variables and formulating variable causal relationships [18]. Data required to build a CLD is typically collected, refined, and validated using qualitative methods that include interviews with stakeholders and observations of the system. Although they have been widely used for consulting activities and policymaking, state-of-the-art CLD models do not focus on the production system design and operational levels but rather try to see the problem more generally from a managerial point of view [19].

4. Methodology

This study was undertaken with companies from the UK high-value manufacturing sector using purposively selected case studies that represented a range of industries that include automotive, aerospace, pharmaceuticals, and electronics. A collection of 80 interviews were performed with different stakeholders from key areas including operations, quality, maintenance, supply relations, customer relations, human resources, and product design. The interviews were focused on identifying the common sources of operational noise and what are the strategies used to mitigate such noises and attempt to improve performance. The interviews were transcribed, and the transcription was used in conjunction with content analysis to identify themes and patterns. Coding of the responses confirmed four high-level sources of operational noise, these are customer uncertainty, supplier uncertainty, internal technical instabilities, and employee variability, and it also identified the domains within the operational noise that are responsible for its amplification. The complex dynamics of the interactions amongst these four major sources requires considerable effort to be understood. This simplistic representation shows that bi-directional mutual cause-effect relations can be found among customers, internally, and with suppliers. A more comprehensive definition of these links in manufacturing systems is provided in the detailed CLD model in Fig. 1. All the identified major sources of operational noise will be explored in this paper, with the exception of employee variability.

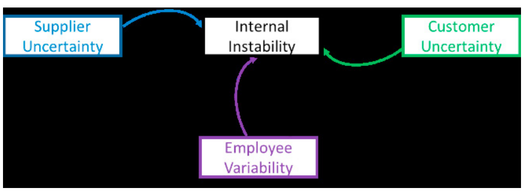

Fig. 1. High-level representation of major sources of operational noise

5. Findings

The main findings of this study are the major sources and domains of operational noise that affect the performance of the manufacturing organizations. As highlighted previously, such operational noises are found internally within the production system and are caused by the suppliers and the customers, as discussed next. High-level causal loop diagrams that map these findings and how they connect will also be presented.

5.1. Internal instabilities

The mapping in Fig. 2 identifies two main loops that interplay the internal behaviour of the system, a balancing loop and another reinforcing one. The reinforcing loop (R2) is driving the system towards increasing production levels, triggered by the customer demand forecast. The production scheduling function generates the ordering of raw materials which arrive after its allocated lead time (delay) as inventory stock which is consumed at the rate of production governed by the machine availability, the yield quality, and the variability of the employees. This dynamic is in interplay with the existence of the balancing loop (B7) where the level of finished goods inventory puts a limit on the quantity of raw materials ordered through adjusting the production scheduling. This implies the importance of accurate and timely information of inventory levels, as well as the effects of the operational noise influencing the production rate, on the internal stability of the production system.

Manufacturing organizations are exposed to multiple sources of operational noise that cause instabilities to the production system. Within the production system, the production strategy is the domain that is most connected to different sources of operational noise, internally and externally. Although externalities influence the production strategy choice, ultimately the quality of decision making on scheduling, prioritization of tasks, the actual and perceived limitations of the processing technologies and the human factors (skills, availability, leadership, etc.) are the sources of internal operational noise. Other domains within the manufacturing organization include the processes, the machines, and how it reacts to external events such as demand change and stock-outs.

Table 2. Domains of internal operational noise and their examples

The domain of operational noise	Examples
Production Strategy	Production scheduling, batch sizes, products mix, production lead time, pull vs push, duration of planning forecast
Processes	Number of processes, manual vs automated, capacity utilization, yield, autonomy
Machines	Availability, setup, equipment age
Employee variability	Productivity, unscheduled absence
Reaction to external events	Demand change, stock-outs, delays

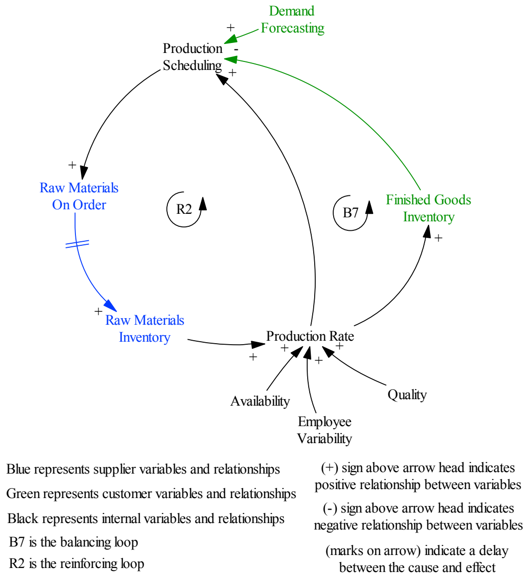

Fig. 2. Causal loop diagram of internal sources of operational noise

5.2. Customer Uncertainty

The CLD in Fig. 3 shows the anticipated dynamic arising from identified feedback loops. The main loop is a reinforcing one (R4) which is driven by orders being fulfilled to satisfy customers requirements. Satisfied customers return after a time delay with more demand and this leads to more orders being placed (R1). The increase in customer demand is also interpreted as demand forecast and used as input to production scheduling and drives the internal production process. A balancing loop (B5) also exists, and it maps the inventory depletion process as more orders are fulfilled to the customers, which has a direct influence on the production scheduling process through existing levels of finished goods inventory.

The strength of the relationship between the manufacturing organization and its customers is one main contributor to operational noise. Within the high-value manufacturing sector, the relationship strength is seen in the duration of the relationship, the level of satisfaction, and the degree of dependency and collaboration between them. Moreover, the richness of the information shared between both parties, as well as the accuracy of this information has been shown to be a main source of noise and contributor to delivery performance.

Table 3. Domains of customer-related operational noise and their examples

The domain of operational noise	Examples
Relationship strength	Duration, customer satisfaction, dependency, number of customers, kanban usage
Delivery performance	OTIF, lead time, quality, frequency of shipments
Information	Demand pattern, forecast duration, order disruption frequency, forecast error

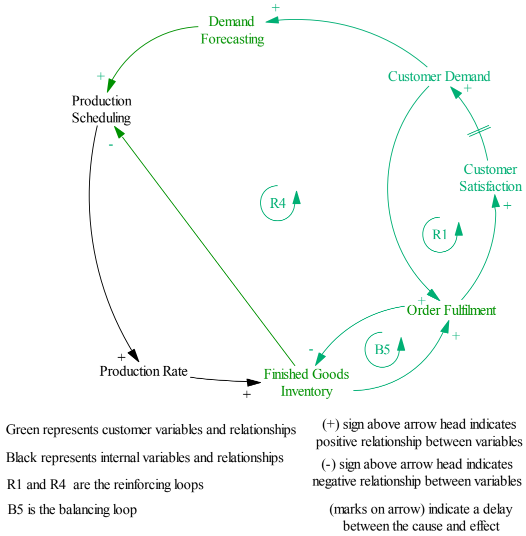

Fig. 3. Causal loop diagram of customer-related sources of operational noise

5.3. Supplier Uncertainty

Fig. 4 shows the interacting feedback loops between the supplier and the manufacturer. The reinforcing loop (R3) maps how the production scheduling function initiates the consumption from the raw material inventory and indicates the quantity of raw materials needed based on the customer demand forecast and internal production processes (See Fig. 2). The quantities of raw material ordered arrive after the expected supplier lead time (delay), which are then used for production as scheduled (B1), and they also adjust the amount of raw material required for ordering (B2). The raw materials have a shelf life due to obsolesce or other factors, therefore after a period (delay) they will be wasted and therefore reduce the stock of inventory (B3) and increase the amount of raw material needed.

The main sources of noise arising from the supplier can also be attributed to the strength of the relationship with the manufacturing organization, and how rich and accurate the information shared between both parties is. In addition, the type of raw material and its shelf-life is another contributor to the instability of the production system.

Table 4. Domains of supplier-related operational noise and their examples

The domain of operational noise	Examples
Relationship strength	Duration, dependency, number of suppliers, choosing criteria, shared improvement activities
Delivery performance	OTIF, lead time, quality, frequency of orders and shipments
Raw material	Raw material shelf life
Information	-Outgoing demand pattern, forecast duration, forecast error, price fluctuations

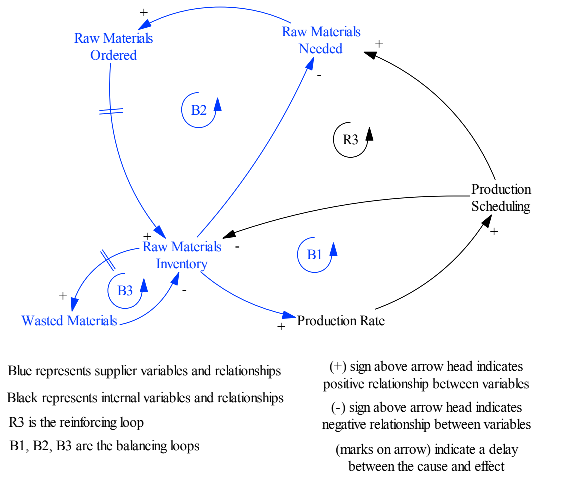

Fig. 4. Causal loop diagram of supplier-related sources of operational noise

6. Conclusions & Future Work

The major sources of operational noise are in an organisation's production system and its design decisions, as well as the relationships that govern the quality and quantity of the information shared between the organisation and its customers and suppliers. Internally, the sources of noise are not only attributed to technical aspects such as the machines or the processes, but also the stability of the human factors. This study implies that for decision-makers to achieve smooth manufacturing flow, the operational noise needs to be managed and controlled in a way that isolates it from affecting the rest of the system. The paper acknowledges that the CLD modelling approach for depicting the interacting relationships is a static one and thus limited in its utility. Transforming the CLD into a dynamic decision-making tool and clearly identifying the relationships between the different variables that amplify operational noise will pave the way towards understanding the impact of operational noise on production systems performance. This will require the quantification of the variables and the relationships between them using different approaches such as group model building and surveys. To enhance our understanding of the effects of operational noise on performance, a simulation model of all the identified variables is required. Simulation will also help in revealing the dominance found in the feedback loops that drive the behaviour of the system. System Dynamics is a suitable simulation approach that adopts stocks and flows and builds on the causal loop diagram mapping technique, and it also uses the feedback principle to assess the cause-and-effect behaviours [20]. The dominance and powerplay of the feedback loops could have completely different effects from one industry to another, as well as the significance of various operational noise on the whole production system, i.e. supplier clustering in automotive is not applicable in aerospace, and therefore the impact from supplier noise will differ. Further exploration of the operational noise in singular industries, as opposed to the focus of this study, which is the high-value manufacturing sector, will reveal industry-specific feedback loops dominance and allow for better understanding of their effects on the production system.

A further enhancement to the simulation model is to integrate it with Industry 4.0 elements (i.e. sensors and digital twins) and feed it with live data regarding the status of the system variables will produce a powerful decision-making tool that enhances control and performance of the production system.

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