Impact of Quality Control on Production System Performance

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Abstract
Quality and production logistics have been traditionally considered as separate fields, both by researchers and industrialists. However, during the design phase of production systems, the decisions taken as an answer to productivity requirements have an impact on product quality; similarly the decisions taken to meet quality requirements affect the productivity performance of the system. The paper proposes an approach to evaluate the overall performance of the system considering both quality and production logistics. The results obtained by the application of the method provide new insight in the relations among the two areas and pave the way to the joint design of production logistics and quality control systems.

Keywords:
Performance Evaluation, Quality Control, Production Logistics

1 INTRODUCTION

With the globalisation of the markets and the growth of competitiveness in the manufacturing sector, quality of products has become a key factor of success. Moreover, the turbolence of demand leads to the continuous need of modifying production targets. In order to rapidly react to these changes, manufacturing systems must be endowed with a right degree of changeability [1] and reconfigurability [2]. In this environment, both quality and logistic performance measures get a fundamental importance in the configuration / reconfiguration phase of production systems. Even if these considerations are widely shared both in the scientific and the industrial research community, quality and logistics have almost always been investigated as two separate research areas.

Logistic performance of production systems have been analysed in the literature by using several tools, mostly developed to predict the main productivity performance measures of manufacturing systems. Simulation [3], analytical methods [4] and logistic operative curves [5] are some of the most commonly used tools. These techniques have different characteristics and fields of application as discussed in [6]. The diffusion of these techniques contributed to create a solid knowledge in the manufacturing system design field. Considerable attention has also been dedicated by researchers to quality issues. Statistical Process Control, SPC, techniques [7], have been developed to monitor the behaviour of production systems, in terms of quality performance. Several techniques have also been proposed to solve design problems such as the location of inspection devices in production systems, the optimisation of control charts parameters and the design of inspection plans. Recent works investigated the impact of the process and the production system design on the quality of the produced parts. Among them, the stream of variation theory [8] has been developed with the objective of determining how the variability of products propagates through the stages of a production system and how the causes for variability can be attributed to different production stages. In these works the impact of different production system configurations is considered, even if logistic performance measures are not directly taken into account.

Recently, some researchers [9] [10] and industrial practitioners have started to recognize the importance of integrating the two fields of quality and production logistics. In particular in [11] cases from General Motors Corporation are reported showing how different system design decisions impact on production quality.

The objective of this paper is to analyse the intersection among quality and productivity and to propose an innovative method for evaluating the overall performance of production systems, considering both Statistical Process Control and system logistics. Indeed, since the quality control system can decide to stop the machines to restore the "in control" conditions, it does affect the production rate of the system. On the other hand, the level of Work In Progress in a system has an impact on the responsiveness of the quality control system. The application of the method provides some results and insight in this new research area and paves the way to the joint design of production systems considering both quality and logistics requirements.

2 SYSTEM DESCRIPTION

In order to capture the behaviour of the system and to describe how quality and productivity performance interact, we propose to model the type of production system monitored by Statistical Process Control, represented in figure 1. The considered system layout is serial, even if the proposed approach could be extended to include many different system architectures, such as assembly / disassembly and split and merge systems. Moreover, only one type of product is considered to be produced in the system, even if the method could be extended to multi-product systems. The system is composed by stations, named M_i and represented by squares, and by buffers, named B_i and represented by circles. Stations can be machining stations, inspection stations or integrated stations. Machining stations are those realising machining operations; inspection stations are those measuring some quality characteristics of the parts produced at one or more upstream machining stations. Integrated stations are those performing both manufacturing and inspection operations. For instance, in figure 1, M_1, M_2 and M_5 are machining stations, M_3 is an

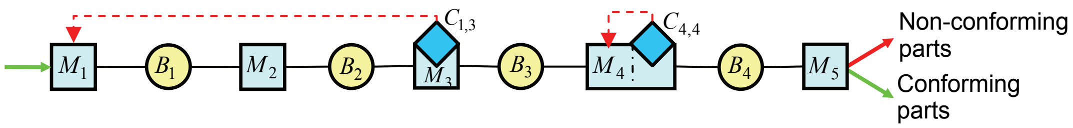

Figure 1: System representation.

inspection station which measures a quality characteristic of parts produced at stations *1* and M_4 is an integrated station measuring features performed at the same machining stage *4*. Each station is considered to be unreliable and subject to multiple failure modes. Buffers are present in the system with the function of decoupling the machines. They are considered to be reliable and have finite capacity. The flow of parts is considered as discrete: raw parts enter the system upstream the first machine M_1, visit all the production stages and they exit the system downstream the last machine M_5 as conforming or non-conforming parts.

According to the SPC theory, the machining stations in the system can produce being either in control or in out of control state. The in control state is normally characterised by a low fraction of non-conforming parts produced, while the out of control state is normally characterised by an higher fraction of non-conforming parts. For instance, the cause for an out of control can be loss of the process settings, wear of tools or fixtures, malfunctioning of some components of the machines, etc. Even if, generally, multiple causes for out of control are possible, in the model we assume that only one out of control mode is possible.

In order to detect out of control conditions, a family of tools named control charts has been developed in the SPC theory. Control charts are logical devices that perform statistical tests of hypothesis basing on data obtained by measuring the produced parts or on data collected directly from the process. In the model we consider only the first case. In the model, control charts are represented as rhombus and named $C_{x,y}$ where x refers to the machining station M_x that processed the monitored feature and y is associated to the inspection machine M_y which measures the product features on which the control chart is based. For instance, in figure 1, $C_{1,3}$ is the control chart based on product data measured at the inspection station M_3 and monitoring machining station M_1. In this case M_1 is said to be *remotely monitored* by $C_{1,3}$. On the contrary, control chart $C_{4,4}$ is based on data measured at the inspection device in station *4* monitoring the machining device in the same station. Therefore, station M_4 is said to be *locally monitored* by control chart $C_{4,4}$. In the model, we consider that features machined at different production stages are independent. Statistical tests performed by control charts are based on the following competing hypotheses:

H_0: the monitored machine is in control

H_1: the monitored machine is out of control

This statistical test is subject to two types of errors, named type I error and type II error. The first error happens when the hypothesis H_0 is rejected while being true, i.e. a false alarm is issued while the machine is in control. The type II error happens when the hypothesis H_1 is accepted while being false, i.e. the out of control condition is not detected.

In order to provide data to be processed by the control charts, inspection plans must be designed. One can design the quality control system to measure all the produced parts, in this case a 100% inspection is performed, or to measure only a fraction of the produced parts, in this case sampling inspection is used. The first policy is normally implemented in those cases in which the time required for inspecting parts is lower than the processing time of productive stations. The second policy is normally followed when inspections are time consuming or are performed manually.

Data collected by the inspection stations are normally used not only for compiling control charts but also to decide whether the inspected parts can be considered as conforming or non-conforming. Indeed the product designer sets the specification limits of the features of the product to guarantee its functionality. Therefore if a feature of a part does not fall within the specification limit the part must be considered as non conforming. Sometimes it is possible to rework non-conforming parts, if the repairing intervention can restore them within the specification limits, otherwise non conforming parts should be scrapped. The method proposed allows to model scrap even if, to simplify the analysis, in this paper scrapping is not considered.

A detailed list of the assumptions of the method follows, underlining both the quality and the productivity aspects.

Out of control state: for the machining station M_i the transition to the out of control state is assumed to happen with probability $p_i^{quality}=1/MTOC_i$ with time to out of control geometrically distributed. The in control conditions are reset with probability $r_i^{quality}$. Not all the machining stations in the model are necessarily subject to out of control.

Fraction of non conforming: according to the specification limits, the fraction of non-conforming parts produced when the process is in control is γ^W, and the fraction of non-conforming parts produced when the process is out of control is γ^O.

Control charts: parameters related to control chart $C_{x,y}$ are the sample size $m(C_{x,y})$, the number of parts between samples $h(C_{x,y})$, the probability of type I error $\alpha(C_{x,y})$ and the probability of type II error $\beta(C_{x,y})$.

Unreliable machines: the stochastic behaviour of failures is traduced by considering geometrically distributed time to failure and repair. The failure and repair probabilities for machine M_i are respectively p_i and r_i in a time unit. Two types of failures are considered: f type failures for which the repairing intervention always resets the machine to the in control conditions, and ϕ type failures for which the repairing intervention restores the machine to the in control or out of control state it was before the failure occurred.

Machines processing times: machining, inspection and integrated stations are considered to have equal deterministic processing times. In cases in which this assumption is too restrictive, additional failure modes of type ϕ can be used to mimic the behaviour of longer processing times, reducing the probability operative state.

Finite capacity buffers: the capacity of buffer B_i is N_i.

3 THE ANALYTICAL APPROACH

The objective of the analysis is to estimate the following system performance measures:

- E^{Tot} the average total throughput of the system, that is the number of parts, both conforming and non-conforming, produced in a time unit;