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Mapping workers' performance to analyse workers heterogeneity under different workflow policies

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ABSTRACT

Manual work in assembly lines allows one to benefit from human reasoning capabilities and to assure the flexibility to adapt to fluctuations in production volume, products mix and reduced product lifecycles. With the objective of quantifying and systematizing the knowledge about the heterogeneity of workers' performance, data was collected in an industrial setting. The results demonstrate a significant variation in workers' performance in terms of speed and variability of the task completion time. A mapping approach is proposed aiming to quantify the workers' performance and visualize performance patterns. Since the human performance is influenced by the setting where the workers perform their job, two real assembly line pacing mechanisms were set and studied: pacing derived from the manual assembly system rhythm and pacing imposed by a fixed time constraint. The type of pacing clearly influences workers' performance (i.e., speed and variability) and revealed a significant influence in the assembly line output. In particular, imposing a fixed and equal time constraint for every worker reduces the heterogeneity of workers' performance and improves the assembly line output.

1. Introduction

In our present time, where products have short life cycles, large model variety and demand uncertainty, the flexibility of the human factor in manufacturing processes is often considered an advantage rather than a problem. While automation has increased productivity and made several stages of product manufacturing less dependent on the labour factor, the use of manual work in assembly is still quite dominant [1–3]. Line-assembly work is kept as a pillar of production systems [4], since it is rather efficient and simple to manage. It allows one to benefit from human reasoning capabilities and to assure the flexibility to adapt to variations in production volumes, product variants and reduced product lifecycles [2].

The term "workflow policy" is used to describe principles of action available to the management for the control of the workflow [5], pacing work being one of them. Pacing comes from the approach of Ford to the assembly systems. Ford's approach was to not only standardize and simplify work, but also impose a rhythm to the workers performing the assembly steps.

According to Dudley [6], the distinction, the distinction between paced and unpaced operations is not always clear, since commonly workers in repetitive tasks are not completely free to work at their own pace but are exposed to speed restrictions of different nature. In an extreme case of pacing, the worker can have his/her performance rigidly paced by a hardware device, where the time available to perform the work is supposed to be equal to its required completion time. In the case of an unpaced work scenario, Dudley [6] considers work situations "in which the speed of working is not determined or influenced by a machine, belt, or other worker". He also refers to other factors which might introduce some degree of pacing such as presenting work in batches or as a continuous supply rate of articles. In the first case, the size of the batch and availability of further batches might introduce some pressure on the work. In the second case, interruptions and the arrival rate itself can influence the time to perform a task. Murrell [7] makes a more detailed distinction between types of pacing: rigid systems and systems with margins. Rigid systems are defined as those where a fixed period of time is set to carry out the task. Systems with margins are often found in lines with conveyor belts in which workers must remove a part from the belt, process the part and return it to the belt before the next part is out of reach. Having simulated the repetitive inspection of electrical components, Murrell [7] concluded that the increasing of the pacing rate tends to increase the number of misses. In addition, the pacing speed for no misses varies greatly (ranging from −7% to −40% of the analysed baseline pacing among

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the observed workers), and the mean output in unpaced conditions is considerably different across participants. Sury [8] supports these findings saying that maximum efficiency in paced work requires different pacing rhythms for different workers. He also concluded that the task time distributions tend to become more "symmetrical" and closer to a normally distributed variable when a rigid pacing is imposed, as previous studies had pointed out [6,7,9].

The conclusions of the aforementioned studies on workers' performance and workflow policies indicate that workers respond to the same stimuli in rather different ways. However, these conclusions are disregarded in the general assumptions used by researchers about the human elements in the manufacturing systems. For example, Boudreau et al. [10] refer that it is often assumed that (1) workers will perform their tasks all at the same pace and with the same amount of variability, independent of the underlying conditions; (2) the workers can be considered independent, meaning that they are not affected by each other; (3) the workers are deterministic and predictable. In the end, simplification of workers behaviour is accepted when designing or modelling an assembly system. Nonetheless, such simplifications can have a significant impact on the accuracy of system performance prediction [10,11], pointing to a research gap between human factors and the operation management practice [12]. Differences in workers' average task completion times can cause blocking and starving in tightly-coupled systems, and underestimating variability will cause the systems models to underestimate congestion [13]. Typically, a worker is not isolated but rather integrated in the assembly system and his/her performance directly affects and is affected by the system itself [14].

Investigating the causes of variability in the task completion times, Doerr and Arreola-Risa [15] published an empirical work suggesting that, even when tasks have significant variations, the worker performing the task can be the most significant source of variability. This points to the need of modelling the variability of task completion time as a function of who performs it. They performed an experiment at a seafood processing line, where workers with homogeneous characteristics (all males with a similar education and experience and trained on the three tasks involved), had to process different sizes of salmon (varying from under 1 kg to more than 5 kg) with interdependencies among workstations. They verified that the worker performing the tasks was a more significant source of variability in task completion times than the inherent variability of the task being performed or the day where the observations took place. Doerr et al. [16] further studied the worker variability and the differences between different workers, proposing a theoretical model in which the workflow policy moderates the relationship between line performance and heterogeneity (differences in average time and variability from worker to worker). Extending the study of the effect of two workflow policies on task time variability within a worker and among workers, Doerr et al. [5] performed a laboratory experiment of an order picking operation. In the first workflow policy, the worker performed the assembly like tasks within the workstation space and the "product" was just passed to the following worker after the task was completed. In the second, workers were allowed to take over the work of a colleague. It was concluded that, even though the participants' performance was more homogeneous in a work sharing policy, such conditions do not necessarily improve the system efficiency.

In terms of differences among workers' performance and their relation to productivity standards (which can introduce a rigid pacing), there is evidence that setting an equal standard for every worker might have a negative impact on motivation. However, it could lead to a decrease in variability around the mean among group members [17]. There is the suggestion that in such cases the slowest workers can sometimes speed up, but it is not assured that the fastest workers will not slow down.

In summary, there is variability in individual performances and evidence for considerable heterogeneity on workers' performance (respectively, within-worker and between-workers performance variability in the terminology used by Doerr et al. [5]). Some workflow policies seem to have a moderating effect both on individual variability and on variations among the workers group members. Nonetheless, the relationship between the amount of variation and how much this variation is affected by the different types of pacing is missing in the existing literature. In addition, an increased understanding of the human factors in production and operations research is of great importance. Human behaviour should not be seen as good or bad. We should instead focus on identifying and characterizing the human factors to improve the accuracy of the existing theoretical models and the general understanding of what is involved and how to have more effective operations [18].

The assembly system output is a result of the performances of the interconnected workers allocated to it. Therefore, the large deviations to the average performance of the group will hamper the system output. In this paper, we investigate the heterogeneity among fully trained and homogenous group of workers, on the basis of data collected in an industrial setting. A mapping approach based on the deviations of the workers' performance relative to the average of the group is proposed to visualize the significance of heterogeneity in performance under different working conditions. In the mapping approach, the differences in performances are mapped in terms of deviations to the average task completion time and average variability of all the workers observed performing the same type of task. This way, the variations in performance can be analysed in a group perspective. Moreover, the dimensionless nature of such maps allows their use to compare different working conditions.

Two empirical studies were conducted in an industrial environment for two different workflow policies aiming to assess their influence on workers relative performance and on the assembly line output. In the first workflow policy (workers paced by the system rhythm), the workers are paced by a common productivity standard for the whole system (system output in parts per hour) and interdependencies result from a serial line with reduced buffer space between workstations. In the second workflow policy (workers paced by a time constraint), the workers are paced by a strict time limit in each workstation. The imposed task time is used as a method to introduce a rigid pacing in the actual assembly system. The workers' performance relative to the average of the group is compared for both policies using the proposed mapping approach.

2. Industrial setting description and data collecting method

The data collection took place in a company that produces kinematic components for automotive interiors such as air vents, ashtrays, door handles, and radio panels, among others. Our industrial partner permitted us to observe assembly lines, dedicated to the kinematic products, in operation. The analysed system is a flow assembly line connected by a loop conveyor which produces radio panels. Several components (such as buttons, tact switches and guide bars) are assembled to the panel and the completed product is inspected before being tagged and packaged to be delivered to the customer.

Readings of the task completion time were made on workers that had been allocated to this assembly system for four weeks previous to the time-study, in order to guarantee their experience in the process, and so safely avoid the learning effects. All the readings were made by the same analyst, using the same digital chronometer. All the observed workers were assured that the measurements were strictly for research purposes and that no personal identification would be registered. During the initial observations, the