Labour Productivity in Mixed-model Manual Assembly Changeovers

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Abstract

In a demand context of mass customisation, Industry 4.0 technologies open new possibilities of increased productivity and flexibility for mixed-model assembly lines. Analytical and parametric analysis is used to better understand the productivity losses of model changeovers as a preliminary step to develop an Assembly 4.0 implementation methodology.

Introduction

The demand trends in recent decades are changing towards the customisation and personalisation of mass produced goods: mass customisation [1]. A dichotomy was traditionally established between automated assembly systems (i.e. employing robots) versus manual or semi-manual assembly (i.e. involving human operators), especially related to productivity – output related to resources used –, and flexibility – the system ability to react efficiently to changes in demand. In consequence, automated systems are typically used for a high volume of relatively similar products – mass production. On the other hand, manual or semi-automatic assembly operations are used for make-to-order or bespoke production, where the high product variability and small batch size does not make it profitable to invest in automation [2].

Rapid and disruptive advances in digital technologies applied to manufacturing lead to the prediction –or expectation – of a 4th Industrial Revolution. The German initiative coined the term 'Industry 4.0' when launching a strategic programme to enhance and accelerate this change [3]. The digital technologies that would enable this change of manufacturing paradigm are namely: Big Data and Analytics, Autonomous robots, Simulation, Horizontal and vertical system integration, the industrial Internet of Things, Cybersecurity, The cloud, Additive Manufacturing and Augmented Reality [4].

Aiming to fill the gap of high-mix low-volume demand, some key enabling technologies of Industry 4.0 would prove useful when dealing with the increasing complexity associated with producing a large number of different products in the same assembly line, by enhancing the collaboration between people and machines [5,6].

To find out how to make the most out of the new digital technologies for assembly operations, it is necessary to understand the factors affecting the productivity of mixed-model assembly lines, with the ultimate goal of establishing the critical aspects that Industry 4.0 solutions need to address. This article focuses on the productivity losses associated with changeovers – the transition from producing one particular model to a different one.

Methodology

Firstly, an analytical model is formulated to establish relationships between several key factors. Secondly, a parametric analysis provides insights into how changes in the key factors and their combination affect the chosen KPI: changeover productivity losses.

Analytical model

In any changeover from one product model (m_{out}) to a new model (m_{in}), the key factors for productivity losses are the number of assembly stations (N_{sta}), cycle time (CT), changeover time (T_{co}), waiting time (T_{wait}), in-process stock units (WIP). Cycle time and the number of assembly stations are not completely independent variables, since they are related by the work content of each model and the line balancing.

The factors relationship with changeover losses can be modelled using simplified Eq. 1, which assumes that changeover times remain the same across all assembly stations for each pair (model in, model out).

$$T_{loss} = N_{sta} \cdot T_{co} + T_{wait} \quad (1)$$

$$T_{wait}^{faster} = (CT_{in} - (WIP + 1) \cdot CT_{out}) \cdot (N_{sta} - 1) \quad (2)$$

$$T_{wait}^{slower} = (CT_{in} - (WIP + 1) \cdot CT_{out}) \cdot \sum_{i=1}^{(N_{sta}-1)} i \quad (3)$$

The waiting time of a particular station varies depending on the cycle time difference between m_{in} and m_{out}: if $CT_{in} > CT_{out}$, then the line is changing towards a faster model (Eq. 2); otherwise it changes towards a slower model (Eq. 3).

Parametric analysis

The software MATLAB is used for calculating the lost and wait time on each assembly station using as input the cycle time of m_{in} and m_{out} as well as the changeover time of each station for each pair of m_{in}, m_{out}.

Expected Results and Conclusion

The expected results from this analysis include (1) identifying the key factors affecting assembly lines changeover time; (2) understanding the importance of the cycle time range (CT_{max}, CT_{min}) of the models that the assembly line can manage with minor productivity losses as a preliminary step to study the implementation of Industry 4.0 collaborative robots; and (3) understanding the effect of sequencing on mixed-model assembly to identify alternatives to decrease the productivity sensitivity to sub-optimal sequencing.

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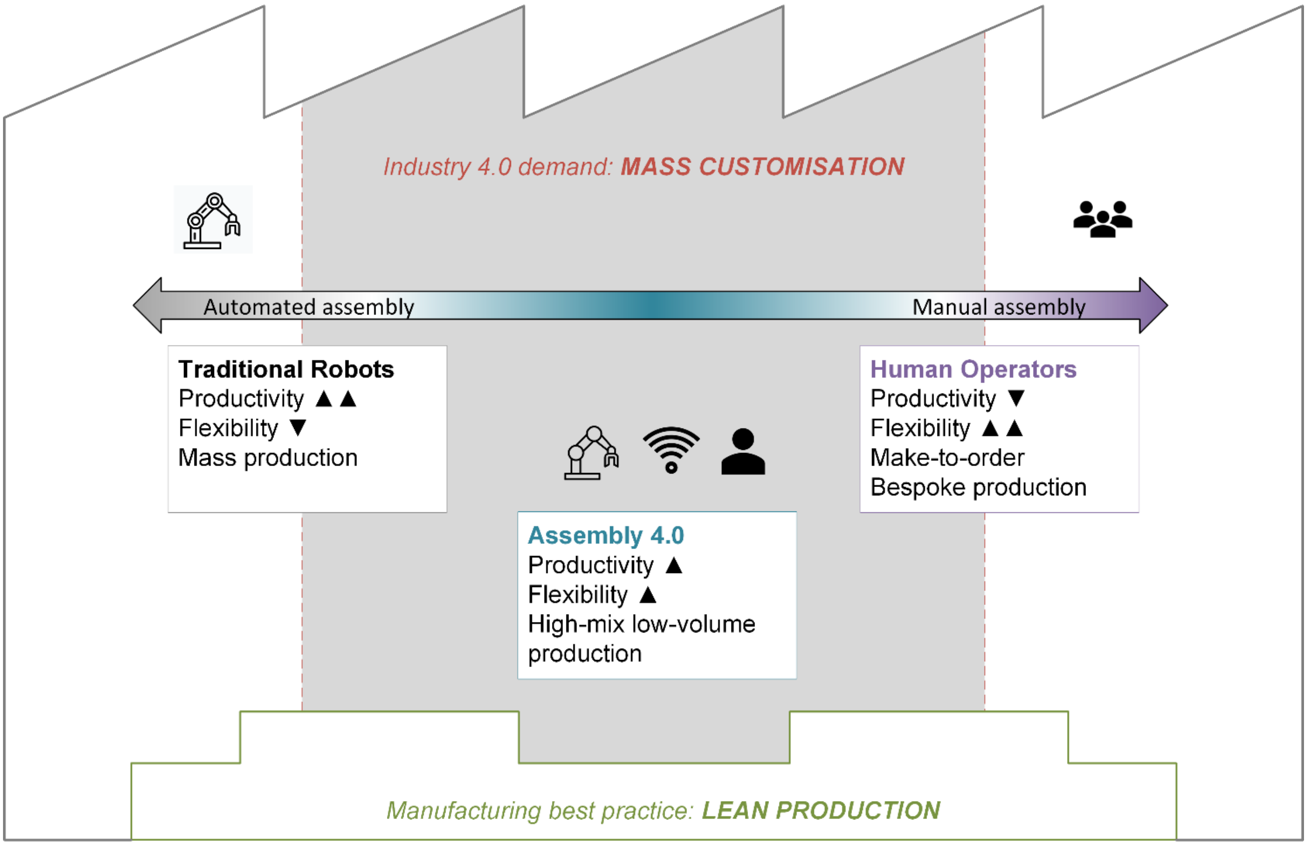

Fig. 1. Assembly 4.0 systems compared to the traditional opposition of human operators vs automated systems.

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