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A Comparison of the Manufacturing Resilience between Fixed Automation Systems and Mobile Robots in Large Structure Assembly

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Abstract

The modern manufacturing industry is undergoing major transformations due to global competition and rapidly changing market demands. Traditional systems with rigid structures are very difficult to reconfigure every time a change in production is required. A promising alternative to these is seen in mobile, self-organising manufacturing systems, where self-deploying and independent entities such as mobile robots are used to facilitate a more reconfigurable assembly process. In addition, an integral part of manufacturing is the transportation of components within the manufacturing environment. Conveyor systems are often unsuitable for moving components that are large, heavy or awkward, making them difficult to use in large structure assembly. Currently, such components are commonly transported by cranes to dedicated automation systems which are seen as expensive and unadaptable. In this paper we investigate the differences in resilience to variations between a set of mobile robots and the widely accepted fixed automation systems under different conditions. Therefore, instead of transporting components or parts to manufacturing equipment we analyse the potential benefits of transporting the equipment to the large parts. By means of simulations, the two systems are compared to one-another in scenarios of identical part arrival times and part processing capacities. Assuming equal production rates, we assess their ability to respond to (1) rush orders, (2) fluctuating arrival times and (3) production mix variations. Currently, there are no specific algorithms for process control of such mobile systems. For this reason we apply the First-In-First-Out task-selection rule. We present a comparison of resilience measures between the systems.

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1. Introduction

The modern manufacturing industry is undergoing major transformations due to global competition and rapidly changing market demands. Due to the ever increasing global demand for customized products, short product lifecycles and frequent market demand fluctuations, manufacturing lines are required to quickly adapt to changes in production (1). A very important measure in modern manufacturing is its resilience, it is a system's ability to mitigate or absorb the effect of a disruption and quickly recover to normal conditions (2). An integral part in manufacturing is the transportation of products within the manufacturing environment. A very common way of doing this is by means of conveyor belt systems (3). However, conveyor belts are not suitable for transportation of large, heavy or awkward products, which are common in large structure assembly. A promising alternative to this is seen in the implementation of mobile robots. Instead of transporting products between manufacturing resources, this approach therefore transports manufacturing resources between products.

Examples of employed fixed automation systems in industry include the ElectroImpact E6000 (4), HAWDE (5), GRAWDE (6) and Kuka FAUB (7). The E6000 is a drilling and riveting system that is used on aircraft wings. HAWDE is a five axis drilling machine that was also designed for aircraft wings. GRAWDE is used for drilling large holes in aircraft wings in order to be able to attach a reinforcement to it. The FAUB was designed to carry out a large proportion of riveting in Boeing 777 fuselages. All of these systems are used for high capacity work in large structure assembly.

An existing alternative for such systems is structure-mounted automation. In this approach, manufacturing equipment is manually placed on the structures where it moves and performs its tasks. Examples of this approach include the mTorres FDH (8) and ElectroImpact Flex Track (9). The FDH uses suction pads to move on structures and performs drilling. The Flex Track is a system that requires tracks to be

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positioned on the structure prior to mounting the drilling system itself. Once mounted, it can move along the tracks to the desired locations and drill holes. The disadvantages of using such systems are their speed of operation and a relatively low extent of autonomy.

A mobile robot can be thought of as a standard robotic arm, but installed on a mobile platform that adds the ability to transport itself anywhere on a shop floor. Since the recent development of industrial standard mobile robots, much research has focused on the core areas of mobile robot operation, such as navigation, localization and perception. However, no direct known work has been published on the scheduling and control of multiple mobile robots. Analogous topics may be considered to be swarm robotics (10), AGV control (11) and a few multi-agent systems (12)-(13) that have some basic transportation or scheduling considerations. In order to do that, it is important to better understand the characteristics and new opportunities when implementing mobile robots as opposed to traditional fixed automation systems with conveyor belts or cranes.

This study focuses on identifying the differences in the ability of the fixed automation systems and mobile robots to respond to the effect of occurring rush orders, fluctuating product arrival times and production mix variations in the production process.

Rush orders have been treated in literature as commonly occurring disturbances that influence the performance of a job shop (14). A rush order can be an order for a prototype, replacement order or some specific customer demand which has been placed after the production plan had already been concluded. Wu and Chen (15) and Chen (16) have produced decision-making models for the acceptance of rush orders. They assert that in order to be accepted, the gained benefit from the completion of the rush order must outweigh the negative effects of changing the current production schedule. It follows that an accepted rush order is more valuable than the regular products in a production line. Therefore in order to minimize disruption costs, it is favourable to complete the rush order and return to normal production conditions as soon as possible.

By fluctuating product arrival times we mean that there is an unsteady flow of arriving products. Production mix variations mean that the arriving products have different work capacities. Thürer, et al (17) explored the impact of different job sizes in their simulations. They state that it is challenging to release all such jobs effectively due to the differences in workload bounding and expected completion times. The allocation of workload becomes more flexible with mobile robots due to the ability to direct several manufacturing resources to the same products, provided that there are no spatial constraints.

The outcomes of this study provide an insight into the characteristics, potential benefits and issues involved with deploying mobile robots. The study serves as a foundation for a doctoral thesis where a n algorithm for self-organization of mobile robots in realistic scenarios will be developed.

2. Methodology

We apply a like-for-like approach where as many factors as possible are equal when comparing a traditional fixed automation system with a mobile robot based approach. Hence, the only major difference between the two scenarios stems from the additional freedom of movement that allows the mobile robots to concentrate around one large work piece when there is high priority set to finish the particular job as soon as possible. For this reason, the mobile robots are expected to handle the rush orders faster, return to their initial jobs sooner and cause smaller tardiness in the assembly process as a whole.

We examine the steady state of production where products arrive to manufacturing systems either at regular intervals or by probability. Identical products arrive to both systems simultaneously. When a product arrives to the workflow, the systems identify whether there are any free workstations available for it to be loaded on. Once loaded, the manufacturing systems are notified that a low priority job has become available. Manufacturing resources carry out their work according to the priority level of each product. Once a product is completed, it notifies the resources of completion and unloads itself from the workstation. During work, manufacturing resources constantly check whether any rush orders have been launched. The flow of a rush order is very similar to the flow of a regular product. The main difference is the fact that rush orders have the highest priority and the systems are required to complete the work on them as soon as possible. This means that all available mobile robots immediately halt their actions in order to complete this particular work piece and then return to continue working where they left from.

2.1 Model Specifications

The software package used for the simulations was NetLogo (version 5.2.1). It was set up as a job shop with a fixed automation system and mobile robots. A distributor was set up to deliver identical products to both systems at identical times. In each simulation run, the number of deployed units was matched between the systems. For example, in a simulation with 4 mobile robots (8 workstations), there were 4 units of fixed systems (also 8 workstations) to match the work capacity. The mobile robots also had a base to return to for the situations where there was no work available for them. In order to temporarily store arriving products that are unable to find an available workspace, a queue was modelled. Products in a queue constantly monitor workspaces and immediately occupy them once available. A product can also be sent to the queue if a rush order arrives and no workstation is available for it. The simulation starts with half of the workstations of each system having work pieces loaded on them.

In most of the simulation runs, the regular work pieces and rush orders require 10,000 seconds of work effort. Except for the final experiment where a mix of different products is analysed. In the mix, products with different capacities arrive to the manufacturing systems. The simulation runs have been designed to last long enough to achieve converged results, as

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