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Ergonomic and technical aspects in the redesign of material supply systems: Big boxes vs. narrow bins

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A R T I C L E I N F O

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A B S T R A C T

This paper presents a design stage comparison of an existing 'big box' material supply strategy common in Swedish manufacturing to a proposed 'narrow bin' approach common in Japanese production systems. Performance times, walking distances, layout space requirements were evaluated for 6 workstations using 'big boxes' of parts along the line. Biomechanical loading on spine and shoulder was estimated for one of the workstations. Comparisons were made to simulated layouts with the 'narrow bin' approach. The use of narrow bin supply yielded significant reductions in rack lengths (−81%), Material Areas (−61%), Walking Distances (−61%), Indirect Work (−24%), and Cycle times (−8%). Peak and cumulative spinal load estimates showed reductions from 29% to 65% with similar load reductions in shoulders and hands. The 'narrow bin' strategy also has implications for the material re-supply system, enables the use of flexible racking and can reduce lift-truck use. Work intensification may increase risks if time-gains are used only to increase direct assembly work repetitions. It is concluded that the narrow bin supply strategy has potential to both improve productivity and reduce risk characteristics of the system. Further field testing is required.

Relevance to industry: Supplying materials in smaller narrower bins poses a potential 'win-win' design tactic with decreased operator risks and improved performance in final assembly when compared to 'big box' supply strategies. The final choice of strategy requires a context-specific assessment.

1. Introduction

The supply of material is, along with people and methods, one of the core necessary elements for production systems (Wild, 1995). Material supply to manual assembly is a key point for performance, and is also a transition between two distinct business processes – logistics and assembly operations. Such transition points pose a possibility for design errors as design priorities can change between these two functions; logistics favouring efficiency in supplying needed parts to the facility, and assembly emphasising the efficiency of assembly of components once they are inside the facility. These two forms of efficiency can be in conflict and typically span two different departments – logistics and assembly – which can cause difficulties in resolving conflicts in design priorities and lead to emergent health hazards for operators (Neumann and Winkel, 2005). Such sub-system transition points can also be sources of risk due to poor working conditions. These organisational conflicts can become even more complicated when responsibility for work-related disorders is considered: Human Resource (HR) departments are frequently held accountable for health and safety results that are heavily influenced by production system design decisions (Neumann et al., 2006; Perrow, 1983). We argue there is a need to consider total system performance, including ergonomics aspects, in order to find optimal solutions between those optimised in favour of any particular department. This paper demonstrates such an approach in the case of designing material supply systems (MSS) for manufacturing systems that provide both efficient material delivery, and also offer good ergonomics and productivity once parts are inside the assembly system.

From an ergonomics perspective, manual material handling (MMH), such as is found in warehousing operations, has long been associated with musculoskeletal disorders (MSDs) (Bernard, 1997). The problem has inspired the creation of common analysis tools like the NIOSH equation(s) (Waters and Putz-Anderson, 1999; Waters et al., 1993) and the use of psychophysical approaches, based on the perceptions of workers of their capabilities for MMH tasks (Snook, 1999; Snook and Cirello, 1991; Wu, 2006) which have

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also been combined with physiological signs to help determine MMH demands under specific circumstances (Li et al., 2009). Epidemiologic research suggests that, in the case of low back pain, disorders are related to both peak biomechanical load and accumulated loading exposures (Norman et al., 1998), both of which are influenced by MMH activities. Case study research has illustrated how the design of material supply strategies and workstation layouts influences operators' biomechanical loading and thus their injury risk (Neumann et al., 2006). In this paper we address MMH issues at final assembly operations in auto sector manufacturing systems.

This study is positioned between two distinct industrial engineering perspectives, namely those of Sweden and Japan. In this comparison the authors draw on their experience visiting production systems and meeting with system engineers in both countries in order to highlight potential differences in approach available for the design of future systems that are both highly competitive and sustainable from the operator's perspective. Sweden has traditionally had to deal with long customer and supplier-side transportation distances. Consequently, there has been an emphasis on efficiency of the logistics system in transporting goods between facilities. In contrast, the Japanese tradition has focussed more on the efficiency of the assembly operations with an emphasis on maximising direct assembly work time for operators (Monden, 1998). As a result the 'Swedish tradition' has emphasised the use of large crates (boxes) for the efficient transportation of parts between and within facilities, and these crates are often then placed directly along the production line for operators to retrieve parts from; often referred to as line stocking – an approach also widely applied in North American manufacturing facilities. We call this the 'Big Box' (BB) material supply strategy. The Japanese approach, on the other hand, favours the use of narrow bins placed close together on racks. This 'Narrow Bin' (NB) approach can give the operator access to many different parts, and part variants, in relatively little space (see Fig. 1, detailed description follows). We present here a comparison of these two material supply strategies in terms of productivity and ergonomics aspects.

A large number of factors must be considered when designing a material supply system (MSS) for final assembly. These include the size, shape, weight, and number of parts and packaging to be handled, as well as the utilisation of space in vehicles, on the shop floor, and in transport vehicles; time efficiency for walking to–from containers, time to acquire parts and handle emballage (packing materials); equipment like lift-trucks needed for warehousing, and the efficiency of moving materials from storage to the shop floor and the management of the system itself (St. Vincent et al., 2005; Wänström and Medbo, 2009). Additionally such factors as flexibility, in terms of accommodating new products, mixed product production, and volume variability in existing products are important factors for some manufacturers (Brown and Bessant, 2003; Wänström and Medbo, 2009) but are not addressed quantitatively in this study. Once in the assembly system the logical layout of parts and the extent to which this matches assembly sequence can also affect assembly operators' performance. The use of layout to provide implicit assembly instructions for operators, as developed for the Volvo Udevalla parallel flow long-cycle assembly operations, is described in more detail elsewhere (Medbo, 1999, 2003). Finally the design of the packaging of components can also affect the efficiency of the return stream of product packaging, for example crates, to the suppliers. If either supplier or customer has a large variety of different material containers, then it becomes increasingly expensive to manage the re-use of these containers. Material supply system design teams must, therefore, consider a wide range of technical and human factors in identifying optimal systems for a particular context. These challenges only increase as the frame of reference for design is expanded to cover the entire firm or supply chain (Dul and Neumann, 2009; Siemieniuch and Sinclair, 1995; Sinclair et al., 1995).

The aim of this paper is to present a modular concept for material supply using 'Narrow Bins' and movable supply racks that poses an alternative to 'Big Box' strategies (described below). We compare this proposed strategy with the existing 'Big Box' material supply strategies observed in two Swedish auto-sector assembly systems. The comparison is made in terms of observed and predicted technical performance of the system and physical workload on the operator – and thus presents an example of a 'virtual ergonomics' analysis approach for an alternative design based on the examination of an existing system. The discussion also addresses a number of factors practitioners should consider in the design of material supply sub-systems.

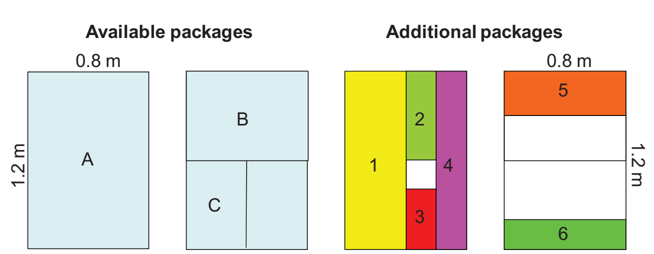

Fig. 1. Illustration of containers (Top View) used in this project with the 'Big Box' and two smaller sized packages currently in use on the left side (identified A, B, and C). To the right additional proposed 'narrow bin' containers (numbered 1–6) are positioned as designed to fit on the same 'Europallet' footprint as the Big Box.

2. Materials and methods

The comparison of BB and NB strategies for MSS design was based on six existing assembly workstations from two different production systems in the auto sector (here forward called system A and system B). Both systems currently use the BB strategy which was compared to the proposed NB approach virtually. Workstations were chosen to be typical representatives of other stations in their respective systems. Workstation cycle times ranged from one to three minutes in system A and four to eight minutes in system B. The sizes of the components were similar in both systems, ranging from a fist size to 0.5 m length, all except one component manually handled. The number of different components located at each workstation ranged between 7 and 22 and the number of components assembled onto an individual product ranged between 3 and 9, not including fasteners. This study focuses on the in-production handling of materials in final assembly. Supply-side efficiency and system stocking are discussed but not analysed directly in this study. Data were gathered from the existing systems, with a BB strategy, and this data was used to conduct a virtual assessment to conduct a design stage evaluation of the NB system.

2.1. Two material supply system strategies

The 'Big Box' (BB) approach is based on a standard 'Europallet' that is 0.8 m wide, 1.2 m long, and uses up to four 4-sided 'collars' resulting in a box height of up to 0.94 m. In addition to this primary size, a few smaller boxes that could fit on this same pallet footprint were also used for some components (see Fig. 1, left-hand side boxes A, B and C). This standard pallet size emerged from US military logistics in World War II and has not changed since. A BB of parts would be delivered to the production line on pallets and either placed on the floor or placed on racks elevating the BB to 0.40 m above ground level – representing the lowest potential