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Analytical Study on a Flexible & Robust Manufacturing System

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Abstract— **A pallet from any of its entries to any of its exits, in each case one pallet at a time. Each of the intermediary switches has two entries and one exit at the left-hand side, while at the right-hand side there are two exits and only one entry. An arrangement of standard modules as in Fig. 1 makes it possible for a pallet to either enter a machine through the lowermost conveyor or else bypass the machine through the middle conveyor. After having bypassed a machine through the middle conveyor, a pallet has two options: it can either proceed in a forward direction to a subsequent machine or move backwards using the topmost conveyor. If, for instance, the lowermost conveyor is already occupied, preventing a pallet from entering the target machine, then the pallet can move backwards and forwards in a circle until the lowermost conveyor is available again. In this way, the entire transportation system serves as a flexible buffer. Most transportation systems induce specific constraints on the flow of material; that is, the sequences in which pallets may visit machines. Let M and M0 be two machines. If in the transport system there is a path from M to M0 then there may be a material flow from M to M0; otherwise, a material flow from M to M0 is impossible. A layout such as the one depicted in Fig. 1, however, does not impose any constraint whatsoever on the material flow; between any pair of machines, there may be a material flow in either direction. For performance reasons, it is often convenient to impose some constraints anyway.**

Index Terms— **Pallet, ntermediary, conveyor, transportation, constraints.**

I. INTRODUCTION

Technology has the potential to act both within and outside the wilderness and outdoor recreation arenas. It cannot only shape our preferences with the natural world but also our expectations of how wilderness and recreation areas should be managed. As technology becomes more mainstream in outdoor spaces, general concerns over its integration fall into three categories: 1) the accelerating rate of technological innovations affecting outdoor recreation and their incorporation into the mass market; 2) the increasing amount of social impacts (conflict, crowding, and displacement) and environmental impacts (increased erosion and wildlife disturbance); and 3) the structure and cultural roles of parks and nature. One realm of innovation changing outdoor recreation preferences is electric-assisted recreation modes, including e-bikes, e-scooters, and e-skateboards. Electric-assist bicycle manufacturing sites are a small but rapidly growing segment of the U.S. bicycle manufacturing site market, not just in the realm of active transportation but as a substantial contributor to outdoor recreation preferences. The regulatory landscape for e-bikes is also evolving as land management agencies at all levels of government, from federal agencies to state and local jurisdictions and special districts, are working to develop policies to address this emerging hybrid technology.

In August 2017, the HB1151 was enacted that updated the law that regulates the operation of bicycle manufacturing sites in the state. Under the new law, ebikes are no longer classified as motorized vehicles, and the definition is expanded to three classes. Class 1 and 2 e-bikes are allowed on bike or pedestrian paths where bikes are allowed unless local governments take action to prohibit them. Class 3 e-bikes are not permitted on bike or pedestrian trails unless local authorities take explicit action to allow them. Definitions E-bikes, also known as electric bicycle manufacturing sites, power bikes, pedelecs, or booster bikes, are bicycle manufacturing sites with an integrated electric motor that does not exceed 750 watts of power. • Class 1: Low-speed pedal-assisted electric bicycle manufacturing site equipped with a motor that provides assistance only when the rider is pedaling and that ceases to provide assistance when the e-bike reaches 20 mph. • Class 2: Low- speed throttle-assisted electric bicycle manufacturing site equipped with a throttle-actuated Introduction 4 motor that ceases to provide assistance when the e-bike reaches 20 mph. • Class 3: Pedal-assisted electric bicycle manufacturing site equipped with a motor that provides assistance only when the rider is pedaling and that ceases to provide assistance when the e-bike reaches 28 mph. Note: class 3 e-bikes are prohibited on all open space trails. Funding and Scope This literature review was funded by four land management agencies in the north Front Range of Colorado.

II. REVIEW OF LITERATURE

Bozer and McGinnis (1992) defines a kit as "a specific collection of components and/or subassemblies that together (i.e., in the same container) support one or more assembly operations for a given product or shop order." Similarly, Johansson (1991) state that "one kit consists of a set of parts for one assembly object." From these definitions it is understood that kitting requires extra handling compared to continuous supply. It should be mentioned that downsizing i.e. breaking down of 5 supplier pallets into smaller containers

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occurs in continuous supply. In these cases the numbers of handlings are the same for kitting as for continuous supply. The part numbers have to be kitted somewhere in the material feeding process. Several kits can be supplied to the assembly station at the same time but the parts needed for each specific assembly object are held ("kitted") together (Bozer and McGinnis, 1992; Johansson, 1991). Also true from the definitions are that no material included in the kit have to be presented separately (presented in line-side storage racks) at the assembly station meaning that kitting is more flexible to changes of the assembly line. Presenting only the required parts for each assembly also reduces the manufacturing floor space as well as increasing the control of work-in-progress through parts visibility and parts accountability on the production floor. (Bozer and McGinnis, 1992)

Kitting is particularly advantageous at the assembly station when the total numbers of components, including number of variants, are many. The reverse is also true, i.e. that kitting is less advantageous in serial lines where each assembly station has few components to be assembled. (Johansson and Johansson, 2006) Kitting is many times not the only material feeding principle to the assembly station. Bozer and McGinnis (1992) mention product complexity and product size as motives for using other material feeding principles than kitting. Components such as fasteners, washers are most commonly also not included in a kit (Bozer and McGinnis, 1992; Baudin, 2004).

In the studied literature a large variety of different solutions considering kitting was examined making it very difficult to describe one pure kitting system. Bozer and McGinnis (1992) observed two types of kits: stationary kits and travelling kits. The stationary kit is delivered to one assembly station where it remains until it is fully consumed. The travelling kit on the other hand travels along side the assembly object and can support several assembly stations before it is consumed. Brynzér and Johansson (1995) further examine the different design options of kitting systems in their report. The kitting can either be performed by an assembler or by a picker (i.e. special category of operators) and the kitting activity can be performed in a central picking store or in decentralized areas close to the assembly stations. Several articles discusses higher picking accuracy when the assembler himself is responsible for the whole job since he has a better understanding for the part numbers included in the assembly operations (Brynzér and Johansson, 1995; Johansson, 1991). The articles also recognize reduced administrative work when the picker and the assembler was the same person.

Other differences discovered by Brynzér and Johansson (1995) in their study of kitting in the manufacturing industry where:

1. Batching policy – instead of picking each kit separately, several kits are picked together in order to reduce walking distance and picking times
2. Zone picking - a picking order is divided into picking zones and hence can be picked simultaneously in different zones
3. Picking information – picking list is the most common picking information for the picker but this system has a high risk for inaccuracy through the picker picking the wrong parts. A display at the storage locations indicating what should be picked is another alternative, which reduces the risk for inaccuracies. Another is to assign each finished product a number, letter or color and displaying this symbol at each storage location.

III. MATERIAL AND METHOD

In a robust manufacturing system, machines must have overlapping capacities. This means that for every manufacturing step there is always more than one machine which, at least in principle, is able to perform this operation. In case of a machine breakdown, this type of redundancy provides the system with the flexibility of diverting a pallet to another machine. Diverting a pallet, however, is not possible without being able to bypass a machine; in particular, with a number of other pallets in the waiting queue of the machine to be bypassed. In general, it should be possible for a pallet to bypass even more than one machine.

DaimlerChrysler developed the concept of a modular manufacturing system that meets this criterion. Fig. 1 shows an example of the new layout. The entire manufacturing M101 M102 M103 M104 M105

1) *A Flexible Manufacturing System*

System is composed of standard modules. Each of these\ modules consists of a machine, three one- way conveyors, two switches and a shifting table. The seven components of a module are arranged as in Fig. 2 . Every switch can move M101

2) *Standard Module*

A pallet from any of its entries to any of its exits, in each case one pallet at a time. In Fig. 1, each of the intermediary switches has two entries and one exit at the left-hand side, while at the right-hand side there are two exits and only one entry.

An arrangement of standard modules as in Fig. 1 makes it possible for a pallet to either enter a machine through the lowermost conveyor or else bypass the machine through the middle conveyor. After having bypassed a machine through the middle conveyor, a pallet has two options: it can either proceed in a forward direction to a subsequent machine or move backwards using the topmost conveyor. If, for instance, the lowermost conveyor is already occupied, preventing a pallet from entering the target machine, then the pallet can move backwards and forwards in a circle until the lowermost conveyor is available again. In this way, the entire transportation system serves as a flexible buffer. Most transportation systems induce specific constraints on the flow of material; that is, the sequences in which pallets may visit machines. Let M and M0 be two machines.

3) *Admissible and Principal Flow*

If in the transport system there is a path from M to M0 then there may be a material flow from M to M0; otherwise, a material flow from M to M0 is impossible.

A layout such as the one depicted in Fig. 1, however, does not impose any constraint whatsoever on the material flow; between any pair of machines, there may be a material flow in either direction. For performance reasons, it is often convenient to impose some constraints anyway.

Definition 1 For every manufacturing system there is a special pre-defined binary relation among machines, denoted by. This relation defines the admissible ordering in which a work piece may visit machines: M0 is an admissible successors of M if M _ M0. A work piece may move from a machine only to one of the admissible successors of that machine; no other successor is possible. The relation is called the admissible flow of material. The admissible flow of material, of course, has to comply with the constraints of the transportation system; however, not every flow that would be possible according to the transportation system alone must be included.

An admissible flow of material may well have cycles. In fact, repair cycles are actually quite common in manufacturing.

However, cycles reduce the overall throughput and thus a backward loop should be avoided whenever possible.

Definition 2 A principal flow of material, _p in symbols, is an acyclic subset of that is, _p is a subset of

_ such that there is no machine M with M _+ p M, where _+ p denotes the transitive closure of _p. This means that the admissible flow _ is partitioned into two disjoint subsets, a major flow _p and a minor flow _ n _p. The motivation behind this distinction is that themajor flow represents the main manufacturing direction. As it stands, Definition 2 is still too general to exactly capture this intuition. To see this, consider Fig. 3. Our intuitiontells us that the solid lines denote the principal flow, whereas the minor flow is depicted by the dashed lines. Definition 2, however, allows for other interpretations as well. According to Definition 2, the minor flow could just include the cycle with length one and the forward edges in the middle.

The principal flow would then cover every other edge, nevertheless being acyclic. Such unintended interpretations can be easily eliminated.
We just have to require that a minor flow from Mn to M02 with Mn 6= M0 must not only be part of the admissible flow, but it also must run in the opposite direction of a path M0; :::;Mn in the major flow. Mathematically, this translates into the following additional constraint:

_ n _p _ (__p) 1: (1)

This states that the minor flow _ n _p is always a subset of the inverse (1) of the reflexive and transitive closure (_) of the principal flow _p. Throughout this work, we assume that this additional condition is always met. Wit this restriction it in fact makes sense to distinguish between forward and backward successors.

Definition 3 Let M and M0 be machines. M0 is called aforward successor of M iffM _p M0, whileM0 is a backward successor of M iff M0 is an admissible successor but not a forward successor ofM.

3. *Self-Organizing Control of Material Flow*

To control the flexible manufacturing system presented in the previous section, we have developed a strictly decentralized approach to manufacturing control, called West.1 In this approach, a specific agent is associated with each work piece, each machine, and each switch. A work piece agent manages the state of the work piece attached to a specific pallet. A machine agent controls the overall material flow through a machine, not just thework in process. To this end, every machine agent manages what we call a virtual buffer.

This buffer includes not only the machine's current work in process, but also the outgoing flow of material; that is, all those work pieces which have already been processed by the machine without yet being able to find an appropriate new machine. A third type of agent, a switch agent, controls a particular switch. It decides which entry to serve first and where to move a pallet.

All these agents constitute parallel processes. These processes are, of course, not independent; they have to be coordinated.

Proper coordination is achieved by special negotiation procedures, which also take place simultaneously. A single work piece negotiates with the machines about which of the machines should process the work piece next.2 The Work piece auctions off its current due operations; it invites machines to bid. Every machine bid includes information about the current state of the machine's virtual buffer. If a work piece awards a specific machine, then this machine will be the next goal of the work piece. The routing of a work piece is organized through a sequence of bilateral negotiations, in each case between the work piece and the next 1West is an abbreviation for the German word Werkst¨ucksteuerung. 2Whenever under stood, we ignore the distinction between an agent and the physical component it controls. work in process output buffer M in P and M out P Conclusion

Switch which the work piece approaches until the work piece eventually has reached its next goal. This is the West approach in a nutshell. The details are elaborated in the following subsections.

3.1. Controlling the Flow through a Machine

Each machine agent manages two buffers, an input and an output buffer. The input buffer contains all those work pieces which awarded the machine and have not been processed yet. This is the machine's work in process. The number of work pieces in the input buffer of machine M is denoted by PM in .

A machine's output buffer tracks all those work pieces that already have been processed by the machine without yet being able to award an appropriate new machine. A work piece thus moves from the input to the output buffer after being processed by the machine. The number of work pieces in M's output buffer is denoted by PM out. The input and output buffer together constitute what we call a virtual buffer. Fig. 4 illustrates the structure of a virtual buffer.

The size of M's virtual buffer is PM = PM in +PM out. PM is always bounded above by a specific constant PM max 2 IN. This constant may vary from machine to machine. It should, however, never exceed the actual capacity of the physical buffer associated with the machine; that is, the section of the transportation system located between two neighboring switches.

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